…lliam H. Crouse

Automotive Chassis and Body
Automotive Electrical Equipment
Automotive Engines
Automotive Fuel, Lubricating, and Cooling Systems
Automotive Mechanics
Automotive Transmissions and Power Trains
Electrical Appliance Servicing
Everyday Automobile Repairs
Everyday Household Appliance Repairs
Home Guide to Repair, Upkeep, and Remodeling
Understanding Science

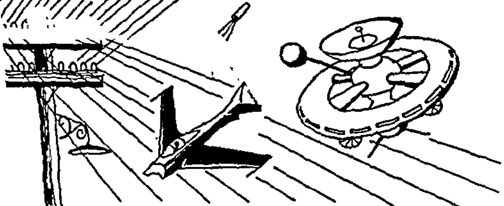
UNDERSTANDING SCIENCE

NEW REVISED EDITION

BY

WILLIAM H. CROUSE

ILLUSTRATED BY JEANNE BENDICK



WHITTLESEY HOUSE

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PREFACE TO REVISED EDITION

A HUNDRED YEARS AGO, a book on science could stand pat for many years. Scientific discoveries and inventions were slow in coming, few and far between. Gradually, however, the tempo has increased. Today, new scientific developments appear with such bewildering rapidity that many people are left far behind in their attempts to keep abreast.

Thus, in these modern times, science books require frequent revision if they are to keep pace. The time has come, because of the many new applications of scientific fundamentals, to bring *Understanding Science* up to date.

It is particularly timely for the revision to appear on the eve of the International Geophysical Year (1957–1958). As part of the activities of the International Geophysical Year, scientists the world over will be working together in the most concentrated assault in history upon the secrets of nature. Many new discoveries about our world and our universe will be made. This new edition of *Understanding Science* will help the reader to understand these new discoveries.

The present edition retains the basic plan of the earlier edition, which is to explain scientific principles and to show how men have used them to invent the telephone, radio, television, motion pictures, airplanes, turbojet engines, rockets, atomic-energy reactors, and many other scientific marvels. The book shows the close relationship between the many branches of science and demonstrates, for example, how an understanding of the human eye leads to easy comprehension of the camera, motion pictures, and television.

If we are to be good citizens in this modern, scientific world,

we must have some understanding of the principles and function of science in modern society. Toward helping provide that understanding, this book is respectfully dedicated.

WILLIAM H. CROUSE

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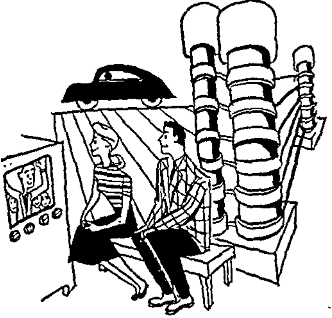
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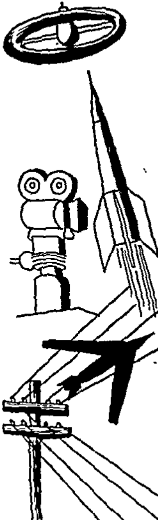
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Chapter One
SCIENCE AND IDEAS



How does color television work? How are we going to put a space platform in an orbit a thousand miles from earth? How do men plan to travel to the moon in rocket ships? What is a solar battery? How does a transistor work?

If you ever ask yourself such questions as these, you have the curiosity of a scientist. Scientists are among the most curious people in the world, continually asking questions about the world around them. But they do more than ask questions. They study and experiment to find the answers.

So if you ask questions and are curious about the things that go on in the world around you, then you have a little of the scientist in you. And you showed the scientific attitude when you opened this book, for you want answers to your questions. You want to know about automobiles, submarines, airplanes, earth satellites, space ships, atomic en-

ergy, television, and the other marvels that have been or are *being invented by scientists.*

In the pages that follow, you will learn something of the ways of scientists and the many things they have discovered. You may be surprised to learn how most of our present-day inventions came about. For we *sometimes think of scientists* and inventors as mysterious men and women working alone in strange laboratories, making magic passes and producing miracles. Yet, as we read on, we will find that the remarkable discoveries which led to our modern inventions were usually the result of many persons' efforts. Every great invention or discovery has a starting point. Someone did some thinking, and experimented, and tested. *An idea* was born. Another person took the idea, did further work with it, changed it, and passed it on to still other people. Sometimes this process took many hundreds of years.

For example, some of the effects of electricity were discovered more than twenty-five hundred years ago. The first steam engine was built more than two thousand years ago. The basic principles of the camera were *known* about eight *hundred* years ago. Airplane principles and a helicopter design were suggested, and the parachute was invented, more than four hundred years ago. Yet it *took hundreds of years* to develop these ideas into practical inventions.

There are many reasons why it took centuries for these inventions to be developed. *One of the*

most important reasons is this: In past centuries, there was little chance for men to communicate with one another. There were no telephones, no reliable postal service. Traveling from one place to another was a long and dangerous business because there were no automobiles or trains, and not many roads. Books were rare, expensive, and hard to get. Therefore, a man who made a scientific discovery had almost no way of telling men in other parts of the world what he had found. Because of this, other men could not benefit from the new discovery. Before these other men could have any success along the same lines, they had to make that same discovery all over again.



You can see that, under these conditions, the outlook for scientific progress was not very bright. Imagine trying to invent the telephone without knowing anything about the principles of electricity or sound! Fortunately, Alexander Graham Bell, who invented the telephone, did not have to discover these principles. Other men who had lived before him had already discovered them. They had explained their discoveries in books that Bell could read.

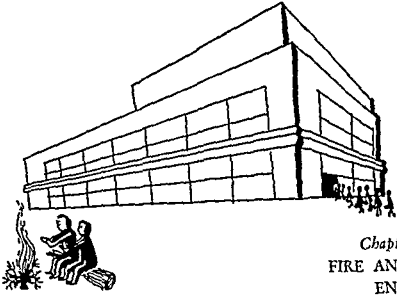
You can see how important it is to scientific workers to learn all about earlier discoveries. An Italian invented an electric battery that would produce a flow of current. A Frenchman discovered the relationship between magnetism and electricity. A German worked out the principles of electric resistance. And an American made use

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Chapter Two
FIRE AND ATOMIC ENERGY

FIRE is man's good and faithful servant. It heats your home. It cooks your food. It makes the steam that runs the engines on which industry largely depends for power. It runs the engines that drive the electric generators which produce most of our electricity. It is used in thousands of processes in industry. A special form of fire, flaming in rapid and rhythmic patterns, furnishes power for the gasoline and oil engines in our automobiles, trucks, farm tractors, diesel trains, and airplanes. There is scarcely any product of human industry—food, clothing, electricity, home-building materials, books, automobiles, electrical appliances—that fire does not help to produce and bring to you.

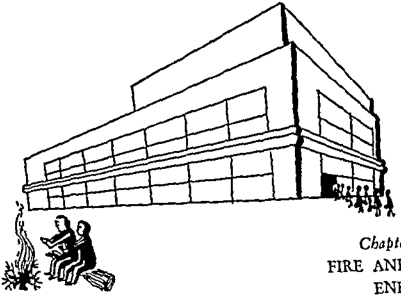
But scientists say this about fire: it is a very wasteful means of getting the heat and energy needed to keep our civilization going. For fire uses

of all these discoveries to invent the telephone.

But this is not an example that stands all by itself. We cannot think of any modern invention that has come about entirely through the efforts of one person alone. All such successes arise from the work of many men and women, of many nationalities and ages, who have laid the groundwork of original discovery.

People like to give credit to individuals for inventions. They say that Watt invented the steam engine, that Edison invented the electric light, that the Wright brothers invented the airplane. It is true that these geniuses can hardly be given enough credit for their wonderful work; but it is also true that none of them could have done their work alone. Other men before them provided the original material—the foundation ideas—that made possible their marvelous discoveries.

As you read the pages that follow, you will see how important ideas have come from the brains of many great men of many nations. No one nation has a monopoly on brains. The free interchange of ideas between the great minds of many nations is necessary if scientific progress is to continue unabated. With new ideas passing between scientists throughout the world, we can count on continuing scientific progress and discovery.



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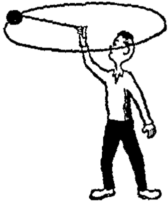
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whole new world of scientific truth for us all.



You need not fear that the atom is too complex to understand. It is as simple as a ball on a piece of string, whirled about your head. All things in our universe are made up of atoms. Your clothes, the wood of the floor and furniture, the glass of the windows, the metal lamps, the tile or brick of the fireplace, and all other things, are made up of about ninety different kinds of atoms.

One particular type of atom is known as iron, another type as oxygen. Others are copper, silver, gold, nitrogen, hydrogen, and sulfur. These different substances are called "elements." The element iron, for example, is made up of one type of atom. The element oxygen is made up of another type of atom. These ninety-some different kinds of atoms can be grouped or compounded in many ways to form the hundreds of thousands of substances we see about us. You can compare this to the letters of our alphabet. There are twenty-six letters in our alphabet, but by putting the letters together in different ways, we can form thousands of words. Likewise, the atoms of the different elements can be put together in many ways to form the many substances that make up our world. On later pages we shall have more to say about this. Meanwhile, let us look more closely at the atom itself and learn what we can about its make-up.

The Atom

A man trying to see a single atom would be somewhat like a man trying to see a single drop of water

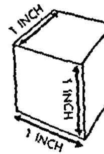
less than one-billionth of the energy stored away in the fuel that is burned.

Well, if that is so, you might say, why don't we find a way to use a larger part of the energy in the fuel? Why not use all the energy? It would be wonderful if we could. For then a pound of fuel would supply enough power to move the largest ocean liner to Europe and back, or to fly the largest airplane around the world. A small fraction of an ounce would heat a house all winter or operate an automobile for many months.

These marvelous things, it seems, may be about to start happening. Already submarines capable of running for months on a few pounds of fuel are driving through the underseas. Ocean liners or airplanes may be next to operate on this new system of using fuel. There is talk of using it to heat homes, to run locomotives and automobiles. And some newly built electric power plants are now running on this new method.

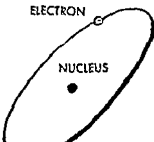
As you have already guessed, the new system we are talking about is called "atomic energy." All of us, of course, have heard something of the atom. We even talk of our present age, the twentieth century, as the atomic age. It is important for us to have some understanding of the atom. Our whole future may depend upon putting the atom to work for us in many ways, some of which we have already mentioned. Understanding the atom helps us also to understand the telephone, radio, television, automobile, airplane, and other scientific marvels of the modern world, thus unlocking a

We will start with a cubic inch of hydrogen at atmospheric pressure (or the air pressure at the earth's surface). If it were at a temperature of 32 degrees Fahrenheit, this cubic inch of hydrogen would contain about 880 billion billion atoms. Next, suppose we could increase the size of this cube until it became large enough to contain the earth. It would then measure 8,000 miles on each side. Now, if the atoms in the cube were increased in size a like amount, we should find that they had become large enough to see—for each atom would now measure about 10 inches in diameter!



You would note, first of all, that the atom is largely empty space. Then, if you could slow down the moving parts of the atom, you would see that it consists of nothing more than two particles! There is one particle at the center. Another particle whirls around this central particle at a tremendous speed—much as a ball on the end of a string might be whirled around your head.

The center of the hydrogen atom consists of a single particle called a "proton." The smaller particle which is whirling madly about the proton is called an "electron." This, then, is the hydrogen atom: a proton in the center, and an electron whirling about it.



THE ATOM ITSELF IS LARGELY EMPTY SPACE

The riddle of electricity

The proton and the electron are two forms of electricity. The proton has a charge of positive electricity. The electron has a charge of negative electricity.

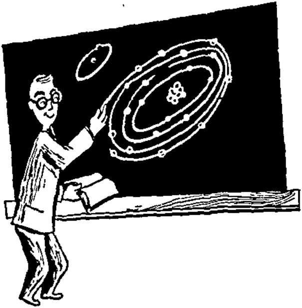
in the ocean while flying many miles above it. He would see the results of a great many drops of water having come together. But he certainly would not be able to see a single drop of water.

In much the same way, we can see the results when a great many atoms have grouped together to form a grain of sand or a drop of water. But there is no method known to science today that can make it possible for us to magnify a drop of water enough to see one single atom—atoms are so very, very small. In just one drop of water there are about 3,300 billion billion atoms! That number is written by putting eighteen zeros after the 3,300! How long do you think it would take you to count that many atoms, if you could count one a second day and night? It would take one hundred thousand billion *years!* We can begin to realize how tiny atoms are when we know it would take that long just to count the number of atoms in a single drop of water.

In spite of its smallness, however, we can get a reasonably clear picture of the atom by using an instrument that is more powerful than any miscroscope. That instrument is our imagination, and with its help we can magnify the atom enough so that we can examine its make-up.

Examining an atom

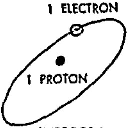
Let us examine the simplest of all the atoms—an atom of hydrogen. Hydrogen is a gas, the lightest-weight gas there is. In fact, no other substance in the world is as light as hydrogen.



Chapter Three

MORE COMPLEX ATOMS

THE HYDROGEN ATOM is the simplest and lightest of atoms. The atoms of other elements are more complex and heavier. The actual weights are, of course, exceedingly small. It would take 754 million billion billion atoms of hydrogen to weigh a pound!



HYDROGEN
THE SIMPLEST ATOM
ATOMIC WEIGHT—1

The next element above hydrogen, as we go from the simplest to the most complicated elements, is helium. Helium, like hydrogen, is a gas. It is heavier than hydrogen because its atoms have more particles in them than the hydrogen atoms do. Next to hydrogen, however, it is the lightest substance known on the earth.

The nucleus of a helium atom contains 2 protons, while 2 electrons circle about it. But the helium nucleus contains two other particles besides the 2 protons. These other particles, while they have the same mass or weight as the protons, have no electric charge. Because they are neutral elec-

When we have said this, we can go no further. For we are up against one of the great mysteries of the universe: the riddle of electricity itself. No one can say—*yet*—just what these basic positive and negative charges of electricity *are*. But this we do know: they are two of the basic building blocks from which the atom is constructed.

Between these two tiny particles, the proton and the electron, there is a powerful attraction—the attraction that is always present between negative and positive electric charges. This attraction tends to pull the electron in toward the proton. Counterbalancing it is the tendency that the electron has to move in a straight line. In other words, if there were no attraction, the electron would fly away from the proton in a straight line. But the attraction between the proton and the electron overcomes this tendency, so that the electron continues to whirl about the proton. This is very much like the combination of forces that are set into motion when you whirl a ball on the end of a piece of string. If the string should break, the ball would fly away from your hand. But if it does not break, the string acts as an attractive force between your hand and the ball. The string keeps the ball moving in a circular path around your hand.

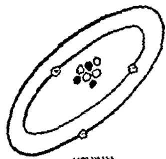
Two important ideas we have discussed in this chapter are (1) all material things in our world are made up of tiny particles called atoms, and (2) the hydrogen atom is made up of two electric particles, a proton and an electron.

(6 and 6, atomic weight 12); nitrogen (7 and 7, atomic weight 14); oxygen (8 and 8, atomic weight 16); and so on. Each atom normally has the same number of electrons revolving about the nucleus as it has protons in the nucleus.

From these facts it should be clear that to change the number of protons and neutrons in an atom is to change the atom from one element into another element. We can visualize some supergenius of the future who will take protons, neutrons, and electrons and combine them in any way he chooses to make iron, or oxygen, or gold, or any other element.

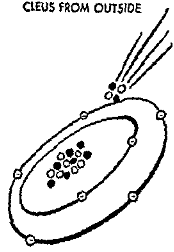
We have not yet progressed as far as that, but already we have changed one element to another with a bombardment of proton or neutron "bullets." Under certain conditions, the bombardment can produce brand-new elements never before detected in nature! These amazing feats are made possible by marvelous instruments that scientists have developed. One such instrument sends a hail of proton or neutron bullets (or often, combination proton–neutron bullets) into a quantity of some element. As the bullets strike the atomic nuclei of the element, they often change the element into a different element.

Nitrogen can be changed into oxygen in this manner, since the bombardment causes the nitrogen atom (with 7 protons) to acquire one more proton, so that it has 8 protons and thus becomes oxygen. This changing of one element into another is called "transmutation." Although trans-



LITHIUM

PROTON–NEUTRON BULLETS BOMBARD THE NUCLEUS FROM OUTSIDE



trically, they are called "neutrons." Neutrons are of vital importance to atoms, since they overcome the natural tendency of the protons to fly away from one another.

Just as there is always a powerful attraction between two *unlike* electric charges, so there is a powerful repulsive force between two *like* electric charges. Two electrons brought closely together will fly apart. Two protons brought together will also fly apart—if neutrons are not present to hold them together. The neutrons supply a sort of binding force, or nuclear "glue," to hold the two protons together in the nucleus of the helium atom.

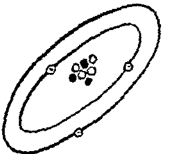
A neutron has approximately the same weight as a proton. Thus, with 2 neutrons and 2 protons, the helium atom weighs four times as much as a hydrogen atom. On this account helium is said to have an atomic weight of 4. The weight of the electrons is neglected in this calculation, since it takes 1,840 electrons to weigh as much as one proton or one neutron.

If, instead of 2 protons, the nucleus of an atom should contain 3 protons, we would normally find 4 neutrons in that nucleus. This combination gives us, instead of a gas, a solid—the metal lithium (lĭth'ĭ-ŭm). Three electrons normally circle the lithium nucleus. The lithium atom, with 3 protons and 4 neutrons, has an atomic weight of 7.

Next come the elements beryllium (bĕ-rĭl'ĭ-ŭm) (4 protons, 5 neutrons, atomic weight 9); boron (5 protons, 5 neutrons, atomic weight 10); carbon

6 and 6, atomic weight 12); nitrogen (7 and 7, tomic weight 14); oxygen (8 and 8, atomic weight 6); and so on. Each atom normally has the same ıumber of electrons revolving about the nucleus as t has protons in the nucleus.

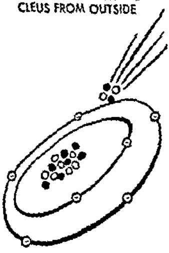
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PROTON—NEUTRON BULLETS BOMBARD THE NUCLEUS FROM OUTSIDE



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mutation seems simple enough in the telling, such work is accomplished only with great difficulty.

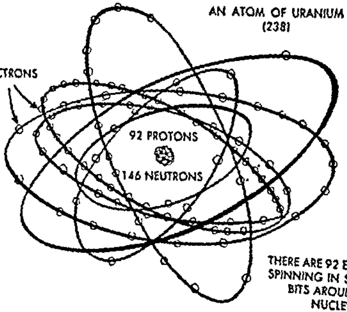
The reason for this lies in the smallness of the nucleus in the atom, as well as in the relatively small number of atoms that populate space. Trying to hit a nucleus with a proton-neutron bullet is somewhat like *trying to hit a particle of dust in the air* with a rifle bullet fired at random, when there are only a few particles of dust per cubic mile. But scientists overcame this difficulty, as we shall see in a later chapter.

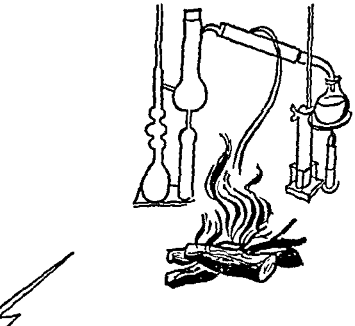
Let us return to our atom of oxygen, and let us add more protons and more neutrons to its nucleus and send additional electrons spinning in orbits about that nucleus. We see the atom becoming more and more complicated as it is changed from an atom of oxygen to one of fluorine, one of neon, and so on up the atomic scale. Finally, we shall have added enough protons and neutrons to have concentrated in the nucleus 92 protons and 146 neutrons, so that the atom has an atomic weight of 238. This atom, with 92 electrons spinning about the closely packed and complex nucleus, is the element uranium, which seems to be the most complicated of the natural atoms.

Man has improved upon nature, however, by creating atoms even more complex than this one. By bombarding atoms of uranium and other heavy elements with nuclear bullets, scientists have stuffed still more neutrons and protons into their closely packed nuclei. They have thus created a whole

series of new "man-made" elements. The names of these elements, and the number of protons their atomic nuclei contain, are listed to the right. The atoms of these synthetic elements are generally quite unstable and soon throw out the excess protons, or even fly apart. This "flying apart," or *fission*, of certain types of atoms is utilized to produce atomic energy, as explained in a later chapter.

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FERMIUM	100
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BEFORE we continue our story of atomic energy, let us discuss a form of energy that has been with us for many ages. This is the energy produced by fire. No one knows what ancient savage ancestor of ours first began to make use of fire, but probably he borrowed it secondhand from the sky; that is, during a thunderstorm, when lightning struck a dead tree and set it afire. This brave savage, overcoming his natural fear and awe of so strange a spectacle, went near the fire and found its warmth pleasing. He learned, furthermore, that the jungle animals were even more afraid of fire than he had been, and that they would keep away from it. Thus, in time, fire came to be not only a source of comfort, but also a means of safety.

Later, some early human being learned how to make fire by rubbing dry wood together, or by striking sparks with flint stones. Man began to cook his food, and finally he found out how to

refine iron and other metals with fire and to shape these metals into tools and ornaments, thus laying the crude foundations for our modern industrial system.

These steps of progress must not be thought of as having happened in a short time. It took many weary centuries for man to learn to adapt fire to his needs in these different ways. But finally man learned the many uses of fire. This knowledge has enabled him to create the advanced civilization in the midst of which we live today. For, as we mentioned in Chapter Two, our civilization is founded on our ability to make and use fire.



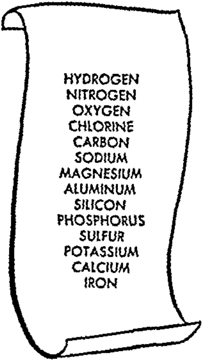
Chemical Reactions

Fire is a chemical reaction, or an action taking place between different chemical substances. Many people think of chemicals as powders or liquids found in a drugstore. But we should think of everything in our world as chemicals. They are made from the elements which have been put together in different forms to make wood or glass or rugs or water, or even the bones, blood, and muscles of our bodies.

Whenever the atoms of different elements combine or react chemically, they form what are called "molecules." An atom of the gas chlorine and an atom of the metal sodium can combine, for example, to form a molecule of sodium chloride (common table salt). Practically everything we see about us is made up of molecules compounded

from the atoms of the different natural elements.

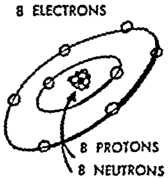
There are some ninety-two natural elements. But most things in our world are largely made up of about fourteen elements, including the gases *hydrogen, nitrogen,* oxygen, and chlorine, and the solids carbon, sodium, magnesium, aluminum, silicon, phosphorus, *sulfur,* potassium, calcium, and iron.



Fire

Fire is a chemical reaction in which atoms of the gas oxygen combine with atoms of certain other elements, such as hydrogen or carbon. We can understand this reaction more easily after examining an atom of oxygen.

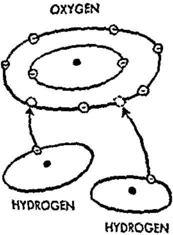
An atom of oxygen has 8 protons and 8 neutrons in its nucleus, with 8 electrons circling about that nucleus. These electrons whirl about the nucleus in two paths, or orbits, one slightly smaller than the other. The inner orbit carries only 2 electrons, while the outer orbit carries the remaining 6 electrons. This outer orbit *could* carry 8 electrons. In fact, the oxygen atom will actually fill out its outer orbit with 2 additional electrons if there are free electrons handy.



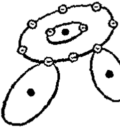
OXYGEN
ATOMIC WEIGHT—16

Fire will take place if the gases hydrogen and oxygen are mixed and ignited. When oxygen and hydrogen atoms mingle with each other, the oxygen atoms will try to take electrons from the hydrogen atoms. But at ordinary temperature, each hydrogen nucleus (which is a single proton) manages to hold fast to its electron.

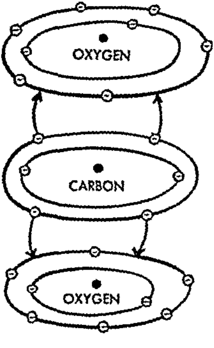
However, if the mixture of the two gases is heated (by a spark or a lighted match, for example), something will happen that will cause the hydrogen atoms to lose their electrons. For the heat, in effect, gives the electrons an electronic "hotfoot," so that they begin to spin much faster in their orbits. Indeed, they begin to circle their nuclei so fast that they fly off and leave the hydrogen nuclei. This is the same thing that would happen if you should whirl about your head very rapidly a ball on the end of a piece of string. The string would break and the ball would fly away.



When the electrons fly away from the hydrogen nuclei, they are attracted toward the oxygen atoms and each oxygen atom immediately acquires 2 of these electrons. This fills up the oxygen atom's outer orbit with 8 electrons. This action gives the oxygen atom a negative electric charge of 2 (one for each electron). Each hydrogen atom, stripped of its electron, has a positive charge of 1. The resulting electrical attraction between these oxygen and hydrogen atoms causes each oxygen atom to trap into combination 2 of the hydrogen atoms to form a molecule. The molecule that is thus formed from 2 atoms of hydrogen and one atom of oxygen has the chemical symbol H_2O, and the common name water. Thus, water is formed from the combustion of the two gases—oxygen and hydrogen. It may seem somewhat odd to get water from fire, but we shall find that water is a common by-product of any fire in which hydrogen takes part.



A MOLECULE OF WATER

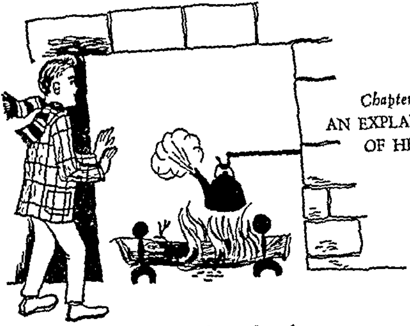


WHEN A CHEMICAL REACTION BETWEEN OXYGEN AND CARBON TAKES PLACE, THERE IS AN EXCHANGE OF ELECTRONS BETWEEN THE ATOMS. THE NUCLEI REMAIN UNCHANGED

Another example of fire

Let us take another example of the chemical reaction known as fire. Most commonly, fire as we know it is the result of oxygen combining with carbon. Air is about one-fifth oxygen. Carbon is a major ingredient in coal, wood, gasoline, oil, or any other fuel. Carbon, with 6 protons and 6 neutrons in its nucleus, has 6 electrons. Two of these circle an inner orbit and 4 move about in an outer orbit. When we "set fire to" a piece of wood, we start the electrons in the carbon atoms moving at increased speed, so that they begin to fly out of their orbits. Each carbon atom thus loses its 4 outer electrons, so that it ends up with a positive charge of 4. The oxygen in the surrounding air immediately snatches up these electrons, each oxygen atom acquiring 2 electrons. So, as you see, it requires 2 oxygen atoms to absorb the 4 electrons that each carbon atom loses. One carbon atom then combines with 2 oxygen atoms to form 1 molecule of carbon dioxide, or CO_2.

It may interest you to know that there is a form of fire going on inside your body at all times. The food that you eat contains carbon. You absorb oxygen from the air that you breathe into your lungs, and this oxygen, carried through your body by your blood, combines with the carbon in a sort of slow, low-temperature fire, which keeps your body warm. Some of the carbon dioxide formed is disposed of through your lungs as you exhale.

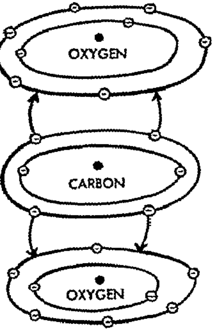


Chapter Five
AN EXPLANATION OF HEAT

WE ALL KNOW that fire produces heat. When you stand before a fire you can "feel" it. And if you put a kettle of water on a fire, the water will soon get hot and start to boil. Then, if you don't take the kettle off the fire, the water will all boil away.

What is this strange thing, heat, that brings about such changes? When we try to explain what it is, we come up against a new idea that may puzzle you for a moment: heat is nothing more than the speeding up of atoms and molecules as they move about in space! You may think that a piece of wood or iron, or a liquid such as water, is pretty solidly packed with molecules, and that there is not much room for the molecules to move around. Strangely enough, however, there is considerable room between the molecules, and they are in constant motion. The higher the temperature, the faster they move.

Another example of fire

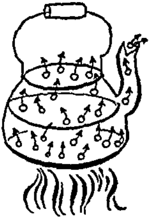


WHEN A CHEMICAL REACTION BETWEEN OXYGEN AND CARBON TAKES PLACE, THERE IS AN EXCHANGE OF ELECTRONS BETWEEN THE ATOMS. THE NUCLEI REMAIN UNCHANGED

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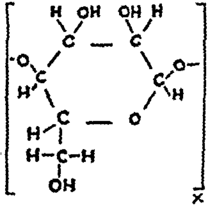
It may interest you to know that there is a form of fire going on inside your body at all times. The food that you eat contains carbon. You absorb oxygen from the air that you breathe into your lungs, and this oxygen, carried through your body by your blood, combines with the carbon in a sort of slow, low-temperature fire, which keeps your body warm. Some of the carbon dioxide formed is disposed of through your lungs as you exhale.

cules will begin to move so fast that they will jump clear of their neighbors and shoot up into the air; that is, the water boils. Soon the kettle will boil dry. Then, if the molecular bombardment continues (if we leave the kettle on the fire), the iron molecules will be bombarded into such rapid motion that they can no longer hold together in the shape of a kettle. The kettle will begin to melt and change to a liquid. If we could continue to increase the temperature of the liquid, its molecules would finally begin to act as the water molecules did; that is, iron molecules would leap clear of their neighbors and shoot up into the air. In other words, the iron would turn into vapor!



This is far from being the entire story of fire and heat. The molecules not only move faster as temperature increases, but also certain forms of *radiation* are produced, which we see as light and feel as heat. More about these radiations in a later chapter.

To get this clear in our minds, let us look at the action in the kettle of water. First we start the fire. Fuels such as wood and coal are made up of molecules. These molecules are, in turn, made up of atoms of such elements as carbon, hydrogen, and oxygen. The most common type of wood molecule, for example, has 6 atoms of carbon, 10 atoms of hydrogen, and 5 atoms of oxygen, and has the chemical formula $C_6H_{10}O_5$.



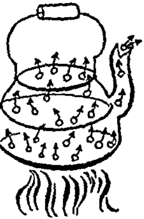
A CHEMIST'S DRAWING OF A WOOD MOLECULE

When the wood is cool, the molecules move slowly and in restricted paths. But when the wood begins to burn, the molecules move very rapidly. In fact, they move so fast that they begin to go to pieces. Then the atoms fly out of their molecular framework. As this happens, the carbon atoms combine with oxygen atoms from the air to form carbon dioxide (see page 28). At the same time, the oxygen and hydrogen atoms in the wood combine to form water.

All this activity causes the newly formed molecules to dart about with speeds up to several miles a second. The kettle above the fire is right in the path of these fast-moving molecules, and thus, the iron molecules in the kettle are bombarded quite hard. This sets the iron molecules into rapid motion. The fast-moving iron molecules now bump the water molecules in the kettle, and the water molecules are therefore set into more rapid motion. If you put a finger into the water, you would say that the water is getting warm.

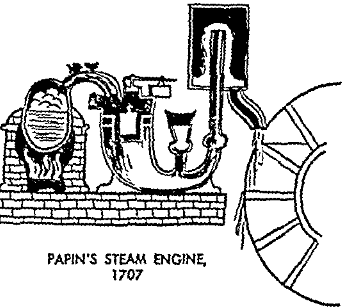
As this action continues, some of the water mole-

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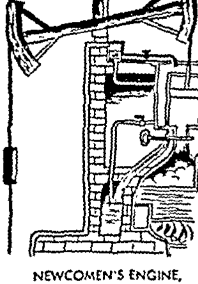


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Chapter Six
PUTTING STEAM TO WORK



PAPIN'S STEAM ENGINE, 1707

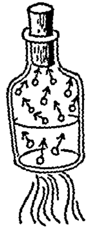


NEWCOMEN'S ENGINE, 1705

THERE IS a story about a Scottish boy named James Watt (1736–1819). The kettle was on the fire, and the water was boiling. As he sat watching the kettle, Watt noticed that the heavy lid was raised by the force under it. He is said to have declared that, if steam could raise the kettle lid, it could be made to do heavier and more useful work. Then, the story goes on, he proceeded to "invent" the steam engine. This account, however, is not entirely true, for it is seldom that any great human invention is the product of only one man's genius.

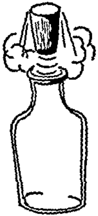
Years before Watt was born, other men were experimenting with the power in the steam from boiling water. The work that these men did, the crude engines that they built, laid the foundations. Then men like Watt came along and improved the crude engines, made them workable. Later, other men further improved the engines. Today, steam

engines are marvels of engineering. Steam, directly or indirectly, turns many of the wheels of industry and drives the huge generators that produce much of our electricity.



What Steam Pressure Is

Steam does its job by developing pressure. When you push against something, you apply pressure to it. Steam applies pressure, too. When water boils, molecules of water move so fast that many of them fly out of the liquid. We call these free-flying molecules "water vapor" or "steam." When many of these fast-moving molecules are confined in an enclosed space, we say that the steam pressure in that space is high. The more molecules there are and the faster they move, the higher the pressure.



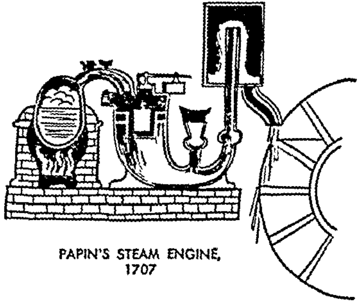
But this does not tell us what "pressure" is. Suppose we take a metal bottle half-filled with water, cork it, and put it over a fire. Presently the water boils, and water molecules fly up into the air in the upper part of the bottle. These flying molecules bump against the sides of the bottle and against the cork. As the water continues to boil, more and more of the molecules leave the water to bombard the sides of the bottle and the cork. Finally, there will be billions upon billions of molecules doing this; that is, the steam pressure will go very high.



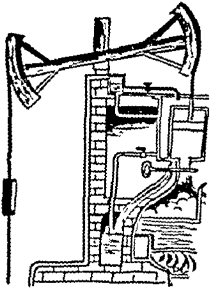
A few molecules hitting the bottom of the cork

Chapter Six

PUTTING STEAM TO WORK



PAPIN'S STEAM ENGINE, 1707



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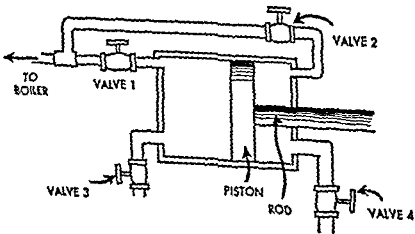
Years before Watt was born, other men were experimenting with the power in the steam from boiling water. The work that these men did, the crude engines that they built, laid the foundations. *Then men like Watt came along and improved the* crude engines, made them workable. Later, other men further improved the engines. Today, steam

as countless water molecules darting about in the cylinder and hammering on the end of the piston. This heavy bombardment makes the piston move.

If we did not have some means of stopping the piston, it would be blown clear out of the cylinder, just as the cork was blown out of the bottle. But this is prevented by the arrangement shown below. Both ends of the cylinder have been closed off, except for an opening through which the piston rod can move back and forth. We have also connected four pipes, with four valves, to the cylinder. The valves are much like the water taps in your kitchen sink. When you turn the water tap *on*, water flows. When you turn it off, the water is shut off.

If we turn valve 1 on, steam from the boiler will flow into the left end of the cylinder. This pushes the piston to the right. Opening valve 4 at the same time allows the air in the right end of the cylinder to move out (or *exhaust*) into the open air.

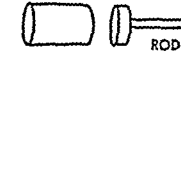
After the piston has moved to the right, closing



would have little effect. But when tremendous numbers of them hammer at it, they soon knock it loose and send it flying with a loud "pop!" If the cork were fastened so tightly that it could not come loose, the steam pressure would continue to build up. Finally the pressure could become so high that the bottle would explode—shattered into bits by the molecular hammering. The force of the explosion would be likely to be so great that anyone standing nearby would be hurt. This is a dangerous experiment which demonstrates the power in steam pressure.

How the Steam Engine Works

Think of a tin can with one end cut out. Then think of a short and slightly smaller can with a rod fastened to it. The smaller can fits into the larger can. You could make it slide back and forth in the larger can by pushing and pulling on the rod.

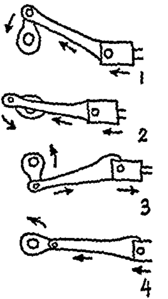


If you did this, you would have put together a rough model of a steam engine. For the steam engine uses a *cylinder* (the larger tin can) and a *piston* (the smaller tin can). Steam pressure is used to move the piston back and forth in the cylinder.

The steam engine has a *boiler;* this is an enclosed chamber where water is boiled. The steam then goes through a pipe to the engine and causes the piston to move. To understand how the steam can make the piston move, think again of the steam

and slides back and forth in the hole as the piston moves back and forth.

The piston rod is connected to a *crosshead*, which is a metal block that slides back and forth in a metal frame. The crosshead is attached to a *connecting rod*, which, in turn, is connected to a *crank pin* on a shaft. A wheel or gear is mounted on the shaft.



AS CROSSHEAD MOVES BACK AND FORTH, THE CONNECTING ROD PUSHES AND PULLS ON CRANK PIN, CAUSING IT TO MOVE IN A CIRCULAR PATH AROUND SHAFT SO SHAFT IS ROTATED

When steam pushes the piston to the right, the crosshead also moves to the right. The crosshead thus pushes on the connecting rod, causing it to push against the crank pin. This forces the shaft to turn, as shown by the arrow at 1. When the piston has moved to the right, as at 2, the engine valve shuts off the steam to the left end of the cylinder. At the same time, the valve admits steam into the right end of the cylinder, so that the piston is pushed to the left, as shown at 3. Then, after the piston has moved to the left, as at 4, it starts to the right again.

As the piston moves back and forth, the connecting rod is pulled and pushed, causing the crank pin to move in a circle so that the shaft rotates. The reciprocating motion of the piston is thus changed into rotary motion.

This rotary motion can be carried from a wheel, or gear, on the engine shaft through a belt or meshing gears to almost any sort of machine.

A typical steam-engine valve

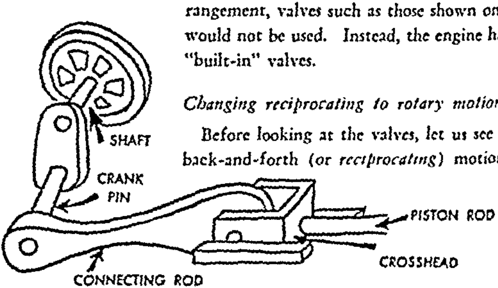
One common type of valve is called the "D-slide" valve. This valve, shaped somewhat like a

valves 1 and 4 and opening valves 2 and 3 causes the *piston to move to the left.* Opening valve 2 allows steam to enter the right end of the cylinder so that the piston is pushed to the left, and opening valve 3 allows the steam in the left end of the cylinder to leave, or exhaust from, the cylinder.

Thus, with the arrangement shown, and with two alert young people to open and close the valves quickly, we could get the piston to move back and forth rapidly. But that job would certainly become monotonous for any person, and, besides, it isn't necessary. For connections can be made between the piston and valves that will cause the *valves to open and close automatically* as the piston moves back and forth. Naturally, with this arrangement, valves such as those shown on page 35 would not be used. Instead, the engine has special "built-in" valves.

Changing reciprocating to rotary motion

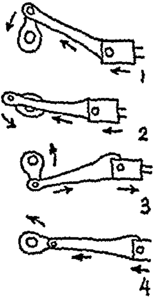
Before looking at the valves, let us see how the back-and-forth (or *reciprocating*) motion of the



piston can make a wheel rotate. You can see how this is done by studying the illustrations. Note that the piston has a rod attached to it. This rod passes through a hole in one end of the cylinder,

and slides back and forth in the hole as the piston moves back and forth.

The piston rod is connected to a *crosshead*, which is a metal block that slides back and forth in a metal frame. The crosshead is attached to a *connecting rod*, which, in turn, is connected to a *crank pin* on a shaft. A wheel or gear is mounted on the shaft.



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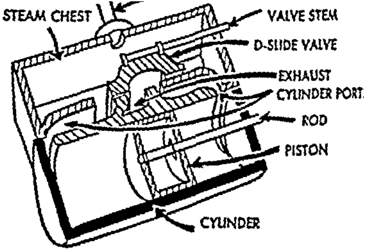
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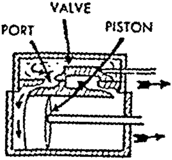
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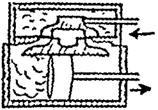
"D," slides back and forth on a flat surface on one side of the cylinder. During this motion the valve uncovers openings, or *ports*, in the engine cylinder to permit steam to enter or to exhaust from the cylinder. Thus, when the valve moves to the right, it uncovers the left-hand cylinder port so that steam can enter the left end of the cylinder from the steam chest. This pushes the piston to the right. At the same time, the slide valve has uncovered the right-hand cylinder port so that the steam in the right end of the cylinder has a chance to escape as the piston moves to the right.

A moment later, when the valve moves to the left, these actions are reversed, so that the piston is forced to the left.

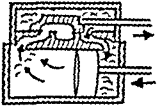
The slide valve is moved by means of a crank pin on the crankshaft and a connecting rod. The rod connects the crank pin and the valve stem.



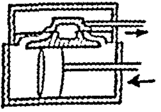
STEAM ENTERS CYLINDER AS VALVE UNCOVERS PORT

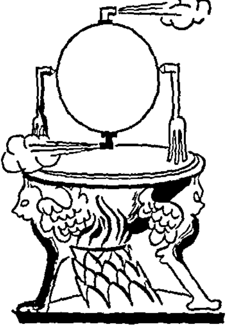


EXPANDING STEAM PUSHES PISTON TO RIGHT VALVE BEGINS TO MOVE TO LEFT



VALVE UNCOVERS PORTS. EXPANDED STEAM EXHAUSTS THROUGH LEFT PORT. STEAM ENTERS RIGHT PORT AND PUSHES PISTON TO LEFT





Chapter Seven

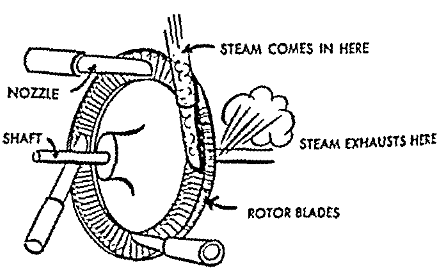
STEAM TURBINES

HERE IS an example of an invention that had to wait many centuries before men discovered a practical means of using it. We are talking about the steam turbine. More than two thousand years ago a man named Hero, who lived in Alexandria, Egypt, made the first steam turbine. It was a steam engine that produced rotary motion. It did not use a piston and cylinder, as do the steam engines described in the previous chapter; instead, the steam from a boiler was carried into a ball which had a pair of bent tubes. The steam shot out of these tubes, forcing the ball to spin on its supports.

For almost two thousand years, men did little with this idea. They could not see how to make the engine do any amount of work. Then, a few hundred years ago, thoughtful men began to work and experiment with this device. But the problem of making it practical eluded them. Finally,

about 1890, De Lavel of Sweden and Parsons of England, working independently and along separate lines, brought out practical steam-turbine designs. The work of these men, and the men who came before and after them, has led to the modern steam turbine which can produce more than 400,000 horsepower. That is, one of these marvelous machines can do as much work as 400,000 horses!

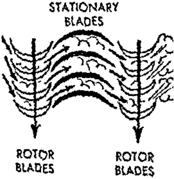
A simple steam turbine is illustrated on this page. The rotor, mounted on a shaft, has many small curved blades around its outside edge. Nozzles direct jets of steam against these blades, causing the rotor to spin at high speed. This rotary mo-



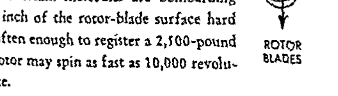
tion can be taken off the rotor shaft by gears, to drive other machinery or an electric generator.

A modern turbine usually has not just one, but a whole series of bladed disks, which together make up the rotor. They are all mounted on a single shaft, so that all rotate together. Between each pair of rotors there is a stationary ring in which is

set a series of blades that curve in the opposite direction from those in the rotors. After the steam has passed through the first disk and given the rotor a powerful rotary push, it *reverses* directions. It then goes through the curved blades on the stationary ring, which *reverses* its direction again, so that it can thrust against the blades in the second disk. In this way the steam goes zigzagging through the turbine, pushing against the rotor blades and changing direction, changing direction again in the stationary blades, and so on. By this process most of the energy in the steam is utilized.



In modern turbines, steam enters at a pressure of as much as 2,500 pounds a square inch. This means that the steam molecules are bombarding every square inch of the rotor-blade surface hard enough and often enough to register a 2,500-pound push. The rotor may spin as fast as 10,000 revolutions a minute.

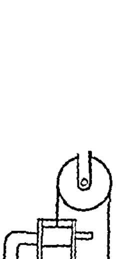


A 400,000-HORSEPOWEI STEAM TURBINE

Chapter Eight
EARLY INTERNAL-COMBUSTION ENGINES



STEAM ENGINES and turbines are "external-combustion" engines, because the fire that causes them to run takes place *outside* the engine. In contrast, the type of engine that furnishes power in our modern automobile is an "internal-combustion" engine, because the fire that causes it to run takes place *inside* the engine. This fire results when gasoline or other fuel is mixed with air in the engine cylinders and is then ignited. The pressure produced in the cylinders moves pistons, and this motion provides the power that turns the wheels and moves the automobile.



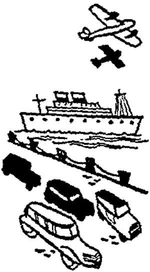
HUYGENS' GUNPOWDER ENGINE

The first internal-combustion engine on record must have been a very dangerous machine to have around; for, instead of using gasoline or some similar fuel, it used gunpowder. This engine was built about 1680, and the brave scientist who experimented with it was Christian Huygens, a Dutchman. Of course, his engine was a curiosity rather than something useful, because it would have been both difficult and dangerous to load and fire the machine repeatedly in order to start the piston and

keep it moving back and forth in the cylinder.

In fact, about ten years later the inventor Dennis Papin decided that the machine would run better if it used easily controlled steam instead of the dangerous gunpowder. And not long after that, reciprocating-piston steam engines were being built and used. Here, then, is another example of a tremendously important invention that was given an early start and then sidetracked for a long period of time.

It was nearly two hundred years later that men once more turned their inventive genius to the internal-combustion engine. Then, in a remarkably short span of time—less than a hundred years—this engine was brought to a state of such high performance that it has become a commonplace necessity in our modern world. Thousands of people speed along the highways, through the sky, and across the sea, day and night, thrust forward by rapidly repeated explosions in the cylinders of internal-combustion engines. Such engines also furnish the power to plow and cultivate fields, to pump water and oil, to drive electric generators, to build highways, to erect skyscrapers. A list of all the services that this engine performs for man would fill many pages.



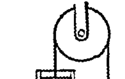
By 1890 men in many countries were working feverishly on this new device, the internal-combustion engine. Soon after the beginning of the twentieth century, the automobile industry, the greatest user of internal-combustion engines, started to

Chapter Eight

EARLY INTERNAL-COMBUSTION ENGINES



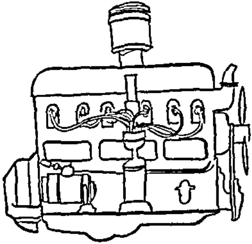
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A 4-CYCLE ENGINE

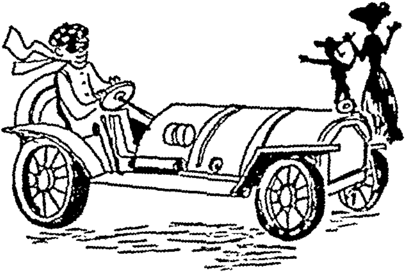


Chapter Nine
HOW THE INTERNAL-COMBUSTION ENGINE WORKS

THE internal-combustion engine is, in certain ways, much like the piston-and-cylinder steam engine. In both, pressure in a cylinder forces a piston to move, and this thrust is carried through a connecting rod to a crank on a shaft, so that the shaft is rotated. But in the steam engine the pressure comes from steam produced by fire or combustion *outside* the engine, while in the internal-combustion engine, the pressure results from fire or combustion *inside* the engine cylinder.

In order to see what an internal-combustion engine looks like, we need only lift the hood of the nearest automobile. But by merely looking at the outside of the engine, we cannot very well understand what makes it operate. We must look down inside the engine for that. If we were to slice through the side of an engine, we should see something like what is shown on the next page. This still won't make much sense to anyone unfamiliar

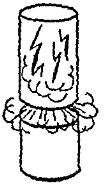
grow. In the United States such famous names as Olds, Buick, Ford, Packard, and Cadillac were already appearing on the name plates and hubcaps of automobiles. European engine and automobile pioneers such as Daimler, Benz, Panhard, Levassor, and Royce were well-known. These and other automobile manufacturers have not only become the leading users of the internal-combustion engine; they are also the ones whom we must thank for most of the improvements that have made this engine the reliable servant of mankind that it is today.



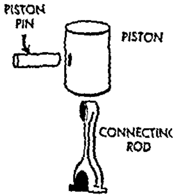
spark occurs, causing an explosion to take place that pushes the piston down.

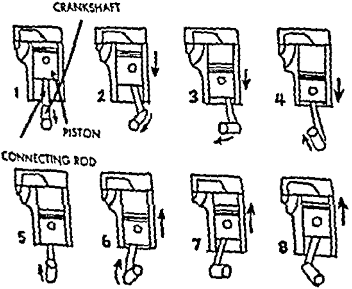
This up-and-down motion of the piston is changed to rotary motion in much the same way as in the steam engine. The piston is attached to a connecting rod. The other end of the rod is connected to a crank pin on the engine crankshaft. When the piston is pushed down by an explosion in the cylinder, the push is carried through the connecting rod to the crank pin. This causes the crankshaft to turn. As the crankshaft continues to rotate, the crank pin pushes the piston back up into the cylinder again. This series of actions is illustrated below.

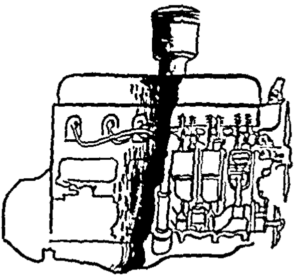
To keep the piston moving up and down, the cylinder must be supplied repeatedly with "charges" of air and gasoline vapor. These charges must be



THE EXPLOSION PUSHES THE PISTON DOWN



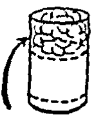




with the engine, because so many different things are shown in the one picture.



THE PISTON FITS INTO THE CYLINDER

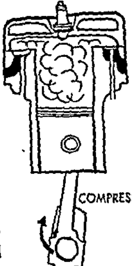


AIR IS TRAPPED AND COMPRESSED IN THE CYLINDER

Let us therefore start with a single cylinder and piston. Most automobile engines have six or eight cylinders; but as all cylinders are alike, we can understand the entire engine if we study one cylinder.

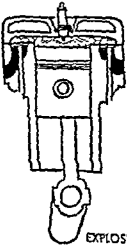
The engine cylinder may be compared to an empty tin can with the bottom end cut out. The piston is a slightly smaller cylinder that fits snugly into the engine cylinder. When the piston is pushed up into the cylinder, it traps and compresses air. Now suppose this compressed air contained gasoline vapor. If a spark occurred, it is easy to see what would happen. There would be an explosion that would push the piston downward. This series of events is about what takes place in the engine cylinder. The piston moves up, compressing a mixture of air and gasoline vapor. A

Next, an electric spark takes place at a spark plug in the top of the cylinder. The gasoline vapor explodes (or *ignites*, as engineers say). This is simply a rapid burning process, such as was discussed in Chapter Four. The carbon and hydrogen in the gasoline combine with oxygen in the air to form molecules of carbon dioxide (CO_2) and water (H_2O). These molecules are fast-moving (combustion temperatures are high, and they bombard the piston head hard. The downward push on the piston head may be more than two tons—the same as though a 4,000-pound weight were suddenly placed on the piston! This gives you an idea of how heavy the bombardment is.



COMPRESSION

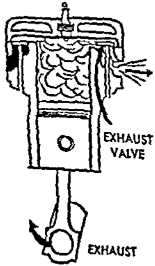
The push on the piston is carried through the connecting rod to the crank pin, causing the engine crankshaft to rotate. In the automobile, the rotary motion is carried through shafts and gears to the car wheels, so that the wheels turn and the car moves.



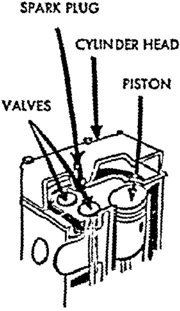
EXPLOSION

After the piston has reached bottom and has started up again, the exhaust valve opens. The upward-moving piston then pushes the burned gas out of the cylinder.

When the piston reaches the top again, the exhaust valve closes and the intake valve opens. The whole round of actions—intake, compression, explosion, and exhaust—then takes place again. These four events continue to follow one another as long as the engine is running.



EXHAUST

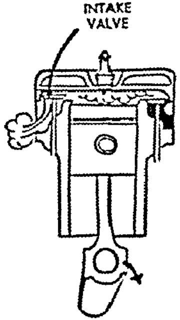


repeatedly exploded by sparks. Also, the burned gas from the explosions must be cleared out of the cylinder.

The repeated "charging" of the cylinder and removal of burned gases is accomplished by valves. There are two valves in the top of the cylinder: an intake valve, which lets in gasoline vapor and air, and an exhaust valve, which opens to allow the burned gas to get out of, or exhaust from, the cylinder.

Each valve is a flat, steel disk on a long metal stem. The disk fits a matching hole in the cylinder. When the valve is seated, it closes off this hole; when it is raised, the hole is open, so that gas or air can pass through it.

The four pictures below and on the next page will help you to understand how the valves and the piston work together in the engine cylinder. The first picture shows the start of the *intake*. The valve to the left, the intake valve, is open. The piston is moving down, and a mixture of gasoline vapor and air is rushing past the valve and into the cylinder, to fill the void left by the descending piston.



INTAKE

As the piston moves down, the cylinder fills with gasoline vapor and air. Then, as the piston reaches bottom, the intake valve closes. The piston starts upward and the mixture becomes compressed. By the time the piston reaches the top position again, the mixture of gasoline vapor and air has been squeezed together into as little as one-eighth of its original volume.

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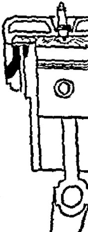
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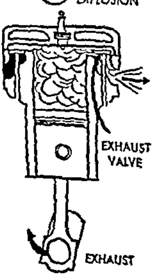
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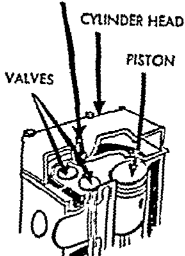
COMPRESSION



EXPLOSION



EXHAUST

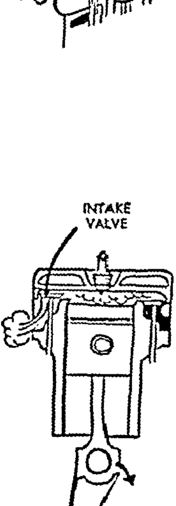


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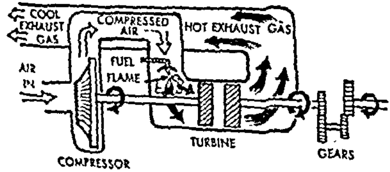


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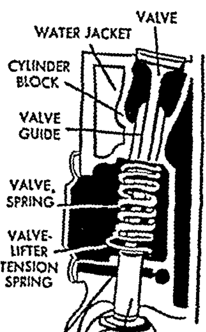
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on trucks and passenger cars. Some engineers say that in the near future most new automobiles will have turbine instead of piston engines.

The turbine engine has a compressor which turns at high speed. The compressor blades, as they spin, force air through a large duct or passage into the turbine section. Before the air enters the turbine, fuel is sprayed into it. This fuel can be gasoline, kerosene, or oil. It burns with a steady flame and produces high temperatures and pressures. The hot, highly compressed gases pour through the turbine wheels and set them spinning. This action is very much like the action that goes on in the steam turbine. One turbine wheel drives the compressor. The other drives a set of gears and shafts that are connected to the car wheels. Thus the rotation of the turbine wheels causes the car to move. After the hot exhaust gases pass through the turbine, they flow around the outside of the air duct from the compressor. The hot exhaust gases thus heat the incoming air. Heating the compressed air improves the efficiency of the turbine.



GASOLINE TURBINE



How the Valves Are Operated

The illustration shows a valve with the other parts that are needed to make it operate. When the valve is closed, the valve spring keeps the valve seated so tightly that no gas or air can leak out of the cylinder. But at the proper time the valve must be opened. This is accomplished by the *camshaft*. The camshaft has a cam, on which there is a *lobe*, or "bump." The camshaft turns when the engine crankshaft turns, because the two are geared together. As the camshaft turns, the lobe moves under the valve lifter, pushing the lifter upward so that the valve is raised, or lifted, off its seat. Then further camshaft rotation carries the lobe out from under the valve lifter, so that the valve spring can reseat the valve.

The camshaft has two cams for each engine cylinder—one for the intake valve, and the other for the exhaust valve. The cam lobes open and close the intake and exhaust valves at the proper times as shown.

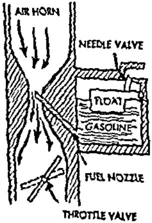
The Turbine Engine

If you were to say that the insides of the gasoline engine we have just been describing are complicated, you would be right. It has pistons, connecting rods, valves, valve lifters, and numerous other parts. In contrast, the turbine engine is rather simple. The turbine engine is coming into use

of the carburetor. When this float bowl has filled up, a metal float raises a needle valve into an opening, shutting it off. This prevents the delivery of any more gasoline until the gasoline level has fallen again.

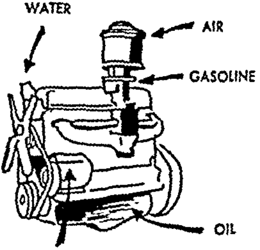
From the float bowl the gasoline moves up through a small tube, or fuel nozzle, that ends in the carburetor air horn. The horn is merely a round tube through which the air moves on its way into the engine cylinders. As it rushes past the end of the fuel nozzle, it draws the liquid gasoline out in the form of fine droplets. The droplets of gasoline quickly evaporate, or turn to vapor, and this mixes with the air as it moves on past the opened intake valve into the engine cylinder.

The "throttle" valve, located in the lower part of the air horn, controls the amount of power that the engine can develop. The throttle valve is connected by rods and levers with the accelerator pedal in the driving compartment of the car. When the driver wants more speed or power, he "steps on the gas"; that is, he pushes the accelerator pedal down. This opens the throttle, and more gasoline vapor and air can move past it into the engine cylinders. This in turn increases the pressure when the mixture is ignited, so that a stronger push is exerted on the piston during each power stroke. More power and higher speed result.



When the driver takes his foot off the accelerator pedal, the throttle valve closes and the engine slows down.

Chapter Ten
RUNNING THE PISTON ENGINE



LET US TALK a little more about the piston-type gasoline engine. These engines have been widely used for many years, and there are millions of them in operation. In order to run this engine must have a supply of gasoline vapor mixed with air. It must also have electric sparks to set the mixture on fire, as we saw in the last chapter. Since combustion produces heat, the engine must be cooled by a cooling system so that it does not get too hot. And the moving parts in the engine must be supplied with lubricating oil so that they will not wear out rapidly.

Mixing the Gasoline and Air

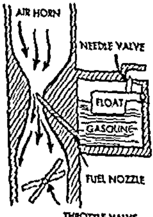
The carburetor, which sits on top of the engine mixes liquid gasoline with air to form the combustible mixture the engine needs to run. A fuel pump, mounted on the side of the engine, draws gasoline from the fuel tank and delivers it to the carburetor.

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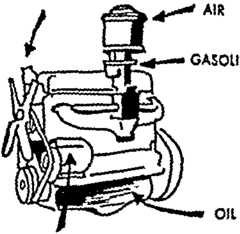
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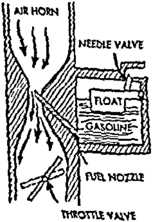
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From the float bowl the gasoline moves up through a small tube, or fuel nozzle, that ends in the carburetor air horn. The horn is merely a round tube through which the air moves on its way into the engine cylinders. As it rushes past the end of the fuel nozzle, it draws the liquid gasoline out in the form of fine droplets. The droplets of gasoline quickly evaporate, or turn to vapor, and this mixes with the air as it moves on past the opened intake valve into the engine cylinder.

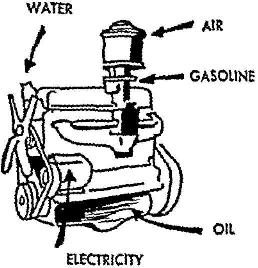
The "throttle" valve, located in the lower part of the air horn, controls the amount of power that the engine can develop. The throttle valve is connected by rods and levers with the accelerator pedal in the driving compartment of the car. When the driver wants more speed or power, he "steps on the gas"; that is, he pushes the accelerator pedal down. This opens the throttle, and more gasoline vapor and air can move past it into the engine cylinders. This in turn increases the pressure when the mixture is ignited, so that a stronger push is exerted on the piston during each power stroke. More power and higher speed result.

When the driver takes his foot off the accelerator pedal, the throttle valve closes and the engine slows down.



Chapter Ten

RUNNING THE PISTON ENGINE



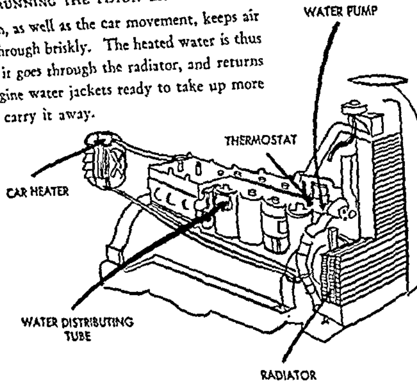
LET US TALK a little more about the piston-type gasoline engine. These engines have been widely used for many years, and there are millions of them in operation. In order to run, this engine must have a supply of gasoline vapor mixed with air. It must also have electric sparks to set the mixture on fire, as we saw in the last chapter. Since combustion produces heat, the engine must be cooled by a cooling system so that it does not get too hot. And the moving parts in the engine must be supplied with lubricating oil so that they will not wear out rapidly.

Mixing the Gasoline and Air

The carburetor, which sits on top of the engine, mixes liquid gasoline with air to form the combustible mixture the engine needs to run. A fuel pump, mounted on the side of the engine, draws gasoline from the fuel tank and delivers it to the carburetor.

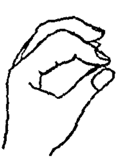
The gasoline enters a small float bowl on the side

engine fan, as well as the car movement, keeps air moving through briskly. The heated water is thus cooled as it goes through the radiator, and returns to the engine water jackets ready to take up more heat and carry it away.



The Engine-oiling System

When you put a drop of oil between your finger and your thumb, they slip over each other more easily than when they are dry. In the same way, oil between the moving engine parts allows them to slip or move easily. The engine-oiling system supplies oil to all the moving parts of the engine so that they are properly lubricated.

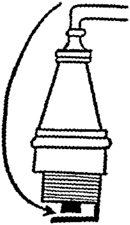


A reserve of several quarts of oil is carried in the oil pan at the bottom of the engine. From there, a pump pulls the oil up and sends it in streams to all the bearings and other moving surfaces in the engine.

Producing the Spark

The mixture of gasoline vapor and air in the cylinder is ignited by a spark. A marvelous little high-voltage electric power plant on the engine called the "ignition system" produces the spark. The electrical principles of this system will be taken up in detail in later chapters. All we need to say at this point is that the ignition system takes the low voltage of the storage battery on the car (6 or 12 volts) and steps it up to as much as 20,000 volts. This high voltage is then applied to a spark plug in the engine cylinder just at the end of the compression stroke. The high voltage causes the spark that sets fire to the mixture of gasoline vapor and air.

THE SPARK JUMPS ACROSS HERE TO IGNITE THE GASOLINE VAPOR



The Engine-cooling System

Heat is produced in the engine by burning fuel. To prevent overheating of the engine, a cooling system is built in to take away the heat as fast as it is produced. The picture shows an engine partly cut away so that the cooling system can be seen.

Around the engine cylinders is a water jacket. This jacket is an open space between the cylinders and the outer shell of the engine. Water circulates through this space, absorbing heat from the cylinders. The heated water is then pumped through the engine radiator, which has a series of air passages. Water goes through some of these passages, and air passes through the others. The

tens of thousands of years ago. In the ages since it oozed from those ancient pine trees, this sap has become covered with earth and hardened into an almost rocklike substance. It has long been much prized for use in jewelry, and in the time of Thales such amber ornaments were often seen.

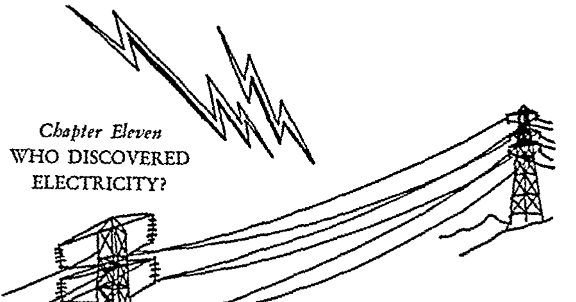
The story goes that one day, when Thales rubbed a piece of amber against his sleeve (perhaps to make it shine more brightly), he found, to his great interest, that it attracted small bits of lint or dried leaves. After further experimenting, he concluded that this attractive force was a property that amber alone possessed. Accordingly, he called this characteristic "elektricity" because, as we have said, the Greek word for amber was *elektron*.

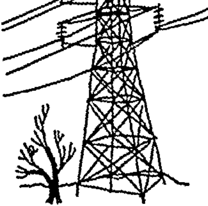


Thales' great discovery remained merely a curiosity for more than two thousand years. About 1600, in the time of Queen Elizabeth, Sir William Gilbert, an Englishman, reported that many other substances besides amber, including glass, sulfur, mica, and diamonds, also had this curious property of "electricity." Naturally, the people of that time had no idea of what electricity was. Some thought that it was a sort of steam that boiled out of the rubbed material and that, when it condensed and went back into the material, it pulled light objects —such as bits of paper or dried leaves—back with it. Others thought of electricity as "rays" that shot out from the rubbed material; these rays, they believed, could penetrate the pores of the paper or leaves and crisscross. Then, when the "rays"

Chapter Eleven

WHO DISCOVERED ELECTRICITY?





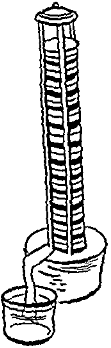
THE WORD "electricity" comes from the ancient Greek name for amber, which was *elektron*. It seems a very odd thing indeed to have named this great servant of mankind after amber, which is the fossilized sap of pine trees. But this is not the oddest feature of man's more-than-two-thousand-year-old study of electricity.

It was about six hundred years before the birth of Christ that electricity might be said to have been discovered. Yet nearly twenty-five hundred years were to pass by before men began to make practical use of electricity, and to design lights, telephones, radios, refrigerators, motion pictures, and the countless other electrically operated devices upon which we depend so much.

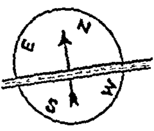
The story of the "discovery" of electricity, some six hundred years before Christ, features the wise man Thales (thā'lēz), of Greece, and a piece of amber. Amber, which looks much like lumps of solidified honey, is sap from pine trees that grew

tric current through wires. In honor of this discovery, the unit of electric pressure, the *volt*, was named after him.

Then, in 1820, the Frenchman André Ampère, using voltaic batteries, discovered a very interesting relationship between magnets and the flow of electricity. Magnets had been known for thousands of years as pieces of iron ore which would pull other pieces of iron to them. If suspended by string, they would swing around until they pointed north and south. But no one had suspected, until Ampère's time, that electric current and magnets had a strange and intimate relationship.



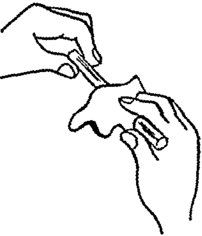
It is true that, a few months before Ampère's discovery, the Danish scientist Oersted (er'stĕth) had reported that the needle of a compass (which is a small magnet) acted strangely if it were held close to a wire through which electric current was flowing. But Ampère went much further. He demonstrated that electric current actually produced magnetism. To prove this, he sent a current of electricity through a coil of wire and showed that the coil then acted exactly like a magnet. The electrified coil would attract pieces of iron and, when it was suspended, it would swing around to indicate north and south, in the same way as a compass needle. Because of Ampère's discovery, the unit of electric current, the *ampere*, was named after him.



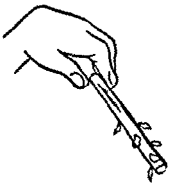
COMPASS NEEDLE SWINGS AROUND AS CURRENT FLOWS THROUGH WIRE

A few years later, a German, G. S. Ohm (ōm), showed that wires offer resistance to electric cur-

shrank, they pulled the paper or leaves back to the rubbed material.



Even the scientists of the next century or two after Gilbert had no clearer idea of what electricity might be, but they made great progress in studying how it acted. The work of the scientists from that time on reminds one of a relay race in which one racer carries the baton around the track for a lap and then passes it on to the next. For each man took the discoveries of those who had gone before him and, from them, moved forward to glorious new discoveries of his own.



Think for a moment about the Italian doctor Luigi Galvani (găl-vä'nē). He published, in 1791, the strange results of some experiments he had been carrying on with dissected frog legs. He had found that the muscles of a frog leg would twitch when touched with two different metals, such as copper and iron, provided that the two metals were in contact. Galvani thought this action resulted from actions inside the muscles themselves.

But a few years later, another Italian, Alessandro Volta, proved that the muscular action had resulted from tiny electric currents produced by holding the two metals together. He proved this by actually constructing a device that would produce electric current. This device, called a "voltaic (vŏl-tā'ĭk) pile," or battery, consisted of a stack of zinc and copper disks with lye-soaked pieces of leather or cloth between them. This voltaic battery created enough electric pressure to push elec-



tric current through wires. In honor of this discovery, the unit of electric pressure, the *volt*, was named after him.

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COMPASS NEEDLE SWINGS AROUND AS CURRENT FLOWS THROUGH WIRE

A few years later, a German, G. S. Ohm (ōm), showed that wires offer resistance to electric cur-

rent and that this resistance varies according to the size and length of wire and the material of which the wire is made. For his great contributions, the unit of electric resistance, the *ohm*, was named after him.



Thus we see that the three fundamental units of measurement used in dealing with electricity, the volt, the ampere (ăm′pēr), and the ohm, were named after three famous scientists, who were Italian, French, and German—*truly a demonstration* of the one world of science.

Meanwhile, men of other nationalities were busily at work delving deeper into the many manifestations of the mysterious substance, electricity. *In the United States, Benjamin Franklin had proved* by a dangerous experiment in 1752 that lightning *is electricity. During a rainstorm, he flew a kite* and drew electric sparks from the wet string. Later, other experimenters who tried this were killed by heavy electric discharges. Franklin put forth the idea that electricity could exist in two states, which he called positive and negative, and that it could flow through conductors much as *water flows in a pipe. This is the basis of our present ideas of electricity.*

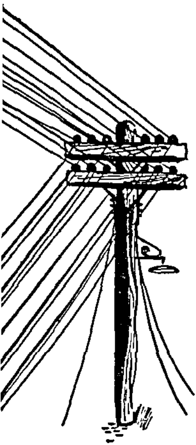
In 1830 the great English scientist Michael Faraday began to ask himself this question: *If electricity could create magnetism, as Oersted and Ampère had demonstrated, couldn't magnetism create electricity?* In other words, was this a reversible action? At the same time, Joseph Henry in the

United States was pondering the same question.

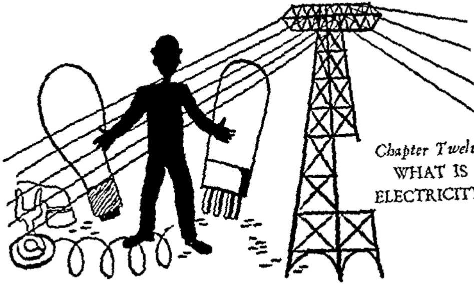
Here were two men, teetering on the edge of a discovery that would change the course of civilization. Seldom has the fate of nations waited so directly on the inventive genius of individual men. For when Faraday, in England, and Henry, in the United States, actually produced electric current by magnetic means, they set off a chain reaction of development that led to our marvelous present-day electrical era, with its electric lights, radios, telephones, and all the other electrical devices upon which so much of our comfort and pleasure depend.

Edison, Tesla, Westinghouse, Morse, Bell, and others were the men who actually put this great discovery to work for mankind. Credit is given to Edison for the development of the electric-light bulb, and he designed and built the first practical central electric power plant. This plant, which was in lower New York City, serviced an area of a square mile—a tremendous project for that time. Tesla proposed using a new form of electric power—alternating current—and he designed equipment to produce, distribute, and use it. Westinghouse backed Tesla and built the electric machinery required to make and use alternating current. Today, alternating current is commonly used, except for certain special machines and processes. We shall have more to say about both alternating and direct current in the pages that follow.

Morse and Bell harnessed electricity so that it



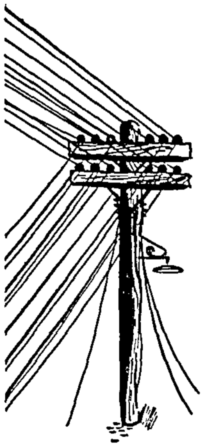
would carry messages over wires by telegraph and telephone, and out of their discoveries grew the works of Marconi and De Forest, who found means of sending messages without wires, or by radio. Then, as a direct result of *their* discoveries, other men were able to give a voice to motion pictures, to send motion pictures through space by television, and to see through fog or darkness by radar. These marvels of modern science will have special attention later in our book. Before we can understand how they work, we must understand something of electricity itself; but as we look into the next chapter, we shall find that this is not difficult, for we have already touched upon the essentials of electricity.



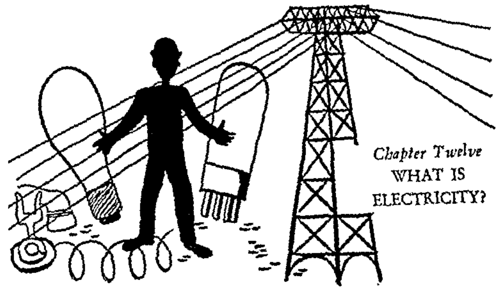
Chapter Twelv
WHAT IS
ELECTRICITY

Only a few years ago, scientists had very vague ideas about electricity. Many of them thought of it as a sort of "fluid" that flowed through wires as water flows through pipes, but they could not understand what made it flow. Many of them felt that electricity was made up of tiny particles of some kind, but trying to separate electricity into individual particles baffled them.

Then, the great American scientist Millikan, in 1909, astounded the scientific world by actually weighing a single particle of electricity and calculating its electric charge. This was probably one of the most delicate weighing jobs ever done by man, for a single electric particle weighs only about half of a millionth of a millionth of a millionth of a millionth of a millionth of a pound. To make up a pound it would take more of those particles than there are drops of water in the Atlantic Ocean.



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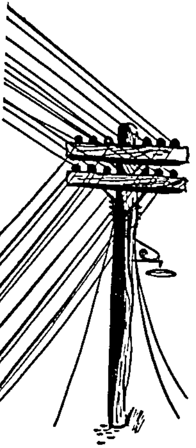


Chapter Twelve

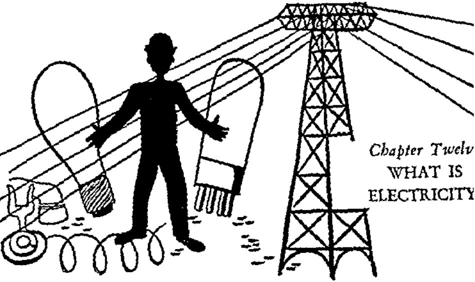
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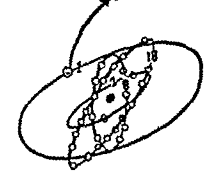


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COPPER ATOM

They are no strangers to us, these electric particles, for we know them as electrons. In earlier chapters we explained how electrons circle the nuclei of atoms. When large numbers of electrons break away from their atoms and move through a wire, we describe this action by saying that electricity is "flowing" through the wire. Yes, the electrical "fluid" that early scientists talked about is nothing more than electrons flowing along a wire!

But how can individual electrons be made to break away from atoms?

And how can these free electrons be made to move along a wire?

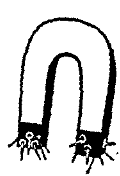


The answer to the first question lies in the structure of the atoms themselves. Some atoms are so constructed that they lose electrons easily. An atom of copper, for example, is continually losing an electron, regaining it (or another electron), and losing it again. A copper atom normally has 29 electrons, arranged in four different orbits about its nucleus. The inside orbit has 2 electrons. The next larger orbit has 8. The third orbit is packed with 18 electrons. And the outside orbit has only one electron. It is this outside electron that the copper atom is continually losing, for it is not very closely tied to the atom. It wanders off, is replaced by another free-roving electron, and then this second electron also wanders away.

Consequently, in a copper wire free electrons are floating around in all directions among the copper atoms. Thus, even though the copper wire looks

quite motionless to your ordinary eye, there is a great deal of activity going on inside it.

If the wire were carrying electricity to an electric light or to some other electrical device, the electrons would not be moving around at random. Instead, many of them would be rushing in the same direction—from one end of the wire to the other.



This brings us to the second question. How can free electrons be made to move along a wire? Well, men have found several ways to do that. One way is chemical. Volta's voltaic pile, or battery, is a chemical device that makes electricity (or electrons) flow in wires. Another way is magnetic. Faraday and Henry discovered how magnets could be used to make electricity flow in a wire.

Magnets

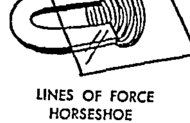


Almost everyone has seen horseshoe magnets—so called because they are shaped like horseshoes. Probably you have experimented with a magnet, and noticed how it will pick up tacks and nails, or other small iron objects. Men have known about magnets for thousands of years.

Several thousand years ago, according to legend, a shepherd named Magnes lived on the island of Crete, in the Mediterranean Sea. He had a shepherd's crook tipped with iron. One day he found an oddly shaped black stone that stuck to this iron tip. Later, when many other such stones were

found, they were called "magnets" (after Magnes). These were natural magnets.

In recent times men have learned how to make magnets out of iron. More important still, they have discovered how to use magnets to push electrons through wires—that is, how to make electricity *flow.*



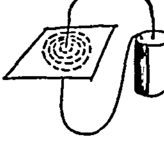
LINES OF FORCE
HORSESHOE
MAGNET

Before we discuss this, there are certain characteristics of magnets that we should know about. If a piece of glass is laid on top of a horseshoe magnet, and if iron filings are then sprinkled on the glass, the filings will arrange themselves into lines. If this same thing is tried with a bar magnet (a horseshoe magnet straightened out), the lines can be seen more easily. These experiments demonstrate what scientists call magnetic "lines of force." Magnets, they explain, work through lines of force that extend between the two ends of the magnet.



LINES OF FORCE
BAR MAGNET

But electrons seem to have magnetic lines of force around them, too. This can be proved by *sticking a wire through a piece of cardboard,* sprinkling iron filings on the cardboard, and connecting a battery to the wire. The filings will tend to form rings around the wire, as a result of the magnetism of the moving electrons (or electricity). So we can see that there is a relationship between moving electrons and magnetism. Magnetism results from the movement of electrons.



LINES OF FORCE
AROUND A CURRENT-
CARRYING WIRE

Of course, electrons are not really "flowing" in the bar magnet, but they are in motion, circling the nuclei of the iron atoms. However, in the mag-

net, the atoms are lined up in such a way that their electrons are circling in the same direction. Perhaps a good comparison might be a great number of boys whirling balls on strings in a clockwise direction around their heads.

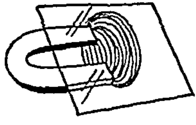
Generators and Motors

Generators use magnetism in producing a flow of electricity (or electrons). In motors, a flow of electricity causes magnetism, which produces rotary motion. This motion can be used to run a lathe or some other machine, a vacuum cleaner, a refrigerator, and so on. Generators and motors may look like rather complicated devices, but they are really very simple. In fact, we have already explained the principles on which generators and motors work. Those principles are:

1. Electrons in motion are called "electricity."
2. Electrons in motion produce a magnetic field.
3. A magnetic field can make electrons move.

In the next chapter, we shall apply these principles and see how simple generators and motors really are.

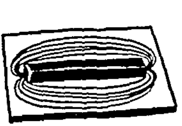
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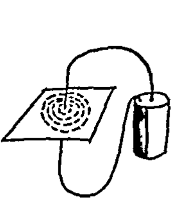
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not flow through this material. This prevents our getting an electric shock if we should touch the wire of a floor lamp, for example.

Resistance

It is easy to believe that a very fine wire would resist the flow of electricity more than would a heavy, thick wire. In the heavy wire there are more free electrons to be pushed and there is more room for them to move about.

A *long* wire has greater *resistance* than a *short* wire, since the electrons have a longer way to go. No matter what the size or length of a wire, however, it does offer resistance to a flow of electricity. The free electrons resist being forced to give up their random movement; they resist being pushed in the same direction along a wire.



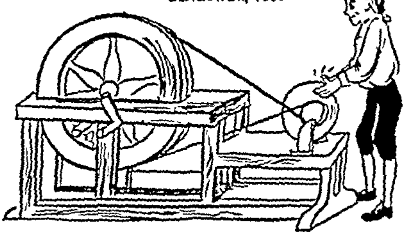
The push that makes the electrons move is called "voltage," after Volta. If there is a long wire through which electricity must be pushed—from Niagara Falls to New York City, for example—the electrons must be pushed very hard. That is, a *high* voltage must be used. The voltage on such long-distance lines may be as much as 230,000 volts. Shorter distances require much lower voltage. The voltage needed for a house wiring system normally is only 110 volts.

Generators

Generators are electric machines that force electrons to move along a wire, so that a flow of elec-

Chapter Thirteen

PUTTING ELECTRICITY TO WORK

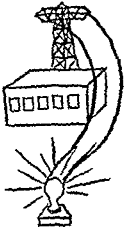


EARLY EXPERIMENTERS *with electricity found* that some materials, such as copper or iron, would carry a flow of electricity (or electrons) with ease. Other materials, like rubber or glass, would not. They did not know the reason for this, but they called those materials that would carry electricity *conductors;* those that would not, they called *nonconductors,* or *insulators.*

Now that we know how atoms are made and what electricity is, we can explain the difference between conductors and insulators. Conductors are materials that lose electrons from their atoms easily. You will remember how copper atoms are continually losing their outer electrons; these free electrons can be pushed along the copper wire so that electricity flows in the wire. Nonconductors, or insulators, are materials made up of atoms that hold on to their electrons. There are few free electrons to be pushed to produce a flow of electricity.

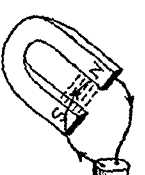
For the sake of safety, electric wires are covered with insulating material, because the electricity will

in a power plant that supplies electricity to many homes and factories must be large enough to produce thousands of amperes of electric current.



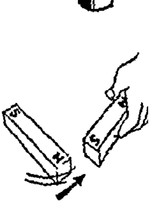
Electricity must have a complete path, or *circuit,* outside the generator; so an electric light in your home, for example, is connected by two wires to the generator in the power plant. Electricity flows *from* the generator through one of the wires. After the electricity passes through the light bulb, it flows back *to* the generator through the other wire. The complete circuit includes both wires and the light bulb.

Motors



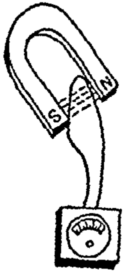
Motors are electrical machines that produce rotary motion when electricity flows through them. You might be surprised if you made a list of the jobs that motors do for you every day. Motors run machines in factories; they run vacuum cleaners, elevators, streetcars, motion-picture machines. An electric motor starts the engine in your automobile.

We can show electric-motor principles if we place a wire between the two ends of a *horseshoe* magnet, and then connect the ends of the wire to the generator. For when electricity flows through the wire, the wire will move out from beneath the ends of the magnet.



We can understand how this movement occurs if we put two bar magnets together, as shown. If you have one magnet lying on the table, and you bring one end of the second magnet toward it, the

tricity results. If you were to visit a modern electric power plant and see its huge generators, it might give you a queer feeling to realize that these tremendous machines were built to push through wires tiny particles that no one ever sees.



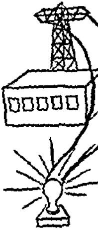
We can make a simple generator with a horseshoe magnet and a loop of wire. If we connect the ends of the wire to an electric meter of the proper kind, and if we then push the wire between the ends of the magnet, the meter will indicate that electricity is flowing.

What happens is this: As the wire moves through the magnetic lines of force, free electrons in the wire are pushed along the wire. The electrons are surrounded with a form of magnetism, and the lines of force act on this magnetism to push the electrons along the wire. We might say that moving the wire through the magnetic lines of force creates a magnetic "breeze" which "blows" the electrons along the wire.

Generators contain many wires so that they can produce a heavy current. Each wire supplies some electrons; the many wires together supply a heavy current of electrons, or electricity. The amount of electric current supplied is measured in amperes, named for Ampère. A small generator might supply only one ampere; however, the actual number of electrons is enormous. A one-ampere generator supplies more than 6 billion billion electrons each second!

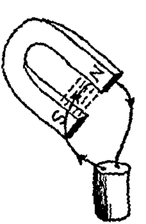
An ordinary electric-light bulb may require ½ ampere of electric current. Therefore, a generator

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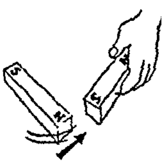
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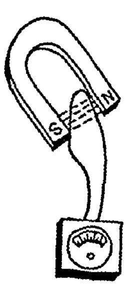
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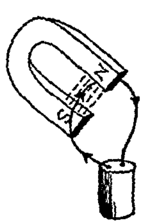
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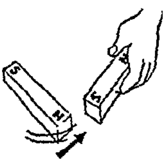
Motors



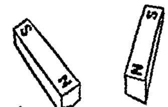
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MAGNETS WILL PULL



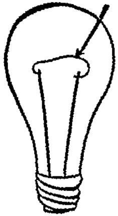
MAGNETS WILL PUSH APART

two magnets will pull together. If you now bring the other end of the second magnet toward the first magnet, the two will push apart.

The movement of electrons in a wire produces magnetism around the wire. When the wire is put between the ends of a horseshoe magnet, the wire will move because the magnetism around the wire pushes against the magnetic lines of force between the ends of the magnet. This is much like the pushing apart of the two magnets, as shown.

In an actual motor, many wires are arranged in a magnetic field so that all of them can be pushed as electricity flows through them. This strong united push causes a rotor to spin. The resulting rotary motion can then be used to operate any mechanism or machinery.

TUNGSTEN FILAMENT



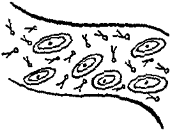
Electric Lights

If you could open an electric-light bulb, you would see two heavy metal wires sticking up from the base, with a very fine wire stretching between their ends. This fine wire, which is called a "filament," is made of the metal tungsten. Tungsten is a conductor of electricity because its atoms allow electrons to escape so that there are free electrons in the tungsten wire.

When the light filament is connected to a generator, electrons try to rush through the filament. The filament is hardly larger than a human hair, however, so not very many electrons are able to get through easily. In spite of that, many electrons

try to push through, because electric pressure, or voltage, is pushing them. As a result, the filament becomes crowded with electrons, and electrons are constantly "jostling" the atoms of tungsten.

Soon the atoms are in violent movement. If you remember what we said in Chapter Five, you will recall that fast atomic or molecular movement is *heat*. Thus, the tungsten filament becomes hot and begins to glow—to give off light.



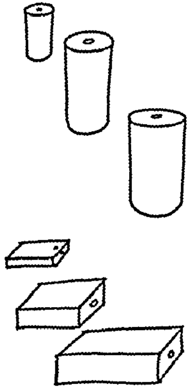
IN THE TUNGSTEN WIRE, ELECTRONS CONSTANTLY BUMP TUNGSTEN ATOMS

The filament is enclosed in the glass bulb so as to keep oxygen in the air away from the filament. If oxygen were present, it would combine with the hot tungsten. In other words, the tungsten would burn up. The bulb keeps the air out and prevents this from happening.

Batteries

Batteries produce electron flow by chemical means—that is, chemical reactions take place inside the battery that result in a flow of electricity. One type of battery is made up of "dry" cells. This is the sort of battery you use in a flashlight. It is dry only in the sense that there is no liquid in it. However, the chemicals inside are damp. Another type is made up of "wet cells"; the cells are filled with liquid. *One common variety* of wet-cell battery is the type used in automobiles.

In a battery, chemical actions take place which produce a flow of electrons, or electric current. These actions crowd electrons onto one battery terminal and take them away from the other bat-


BATTERIES

tery terminal. When a wire is connected between the two terminals, the electrons (or electric current) will flow through the wire. They will flow from the terminal having many electrons to the terminal that lacks electrons. After a certain amount of current has been taken out, the battery cells are run down, or *discharged*. Dry cells cannot be recharged; after they have run down they are worn out and must be thrown away. However, wet-cell batteries such as those used in automobiles can be recharged. During recharging, current is forced back through the battery so that the chemical actions are reversed. This brings the battery up to charge again.

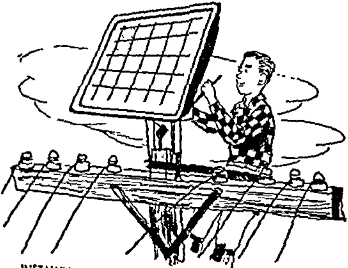
The solar battery

The solar battery "makes" electricity from sunlight. It is a new invention which had its first practical workout in 1955. In that year a solar battery was placed on top of a telephone pole and connected to a telephone system. It furnishes enough electricity to operate several telephones. Inside the battery there are a number of disks made of the element silicon. The disks are connected by wires. When the sun shines on the disks, they give off electrons. This is the "photoelectric effect" which is explained on pages 137 and 138. The electrons flow in the wires to become an electric current.

Since the solar battery produces electric current only when the sun is shining, the system must also use chemical batteries of the type mentioned in

the preceding paragraphs. The chemical batteries supply current at night. Then, during the day, the solar batteries supply the current and also recharge the chemical batteries.

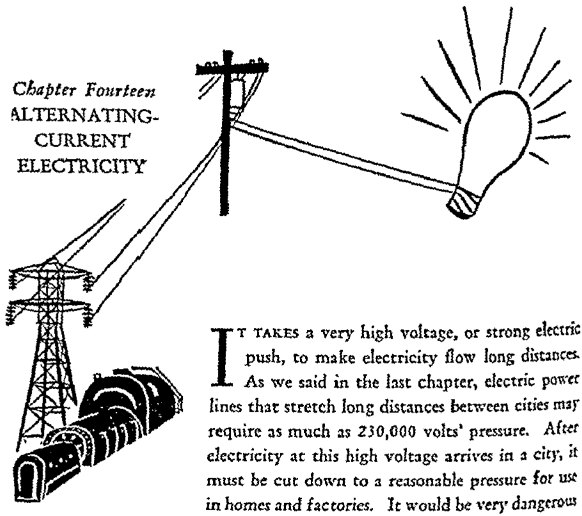
This may appear to be a great deal of trouble for so small an amount of electricity; yet we must remember that the first electric generators were small and feeble, while modern generators produce enormous amounts of electricity. In the same manner, as scientists continue to experiment with solar batteries, they may some day find ways to produce huge amounts of current from them. If this should happen, you may have, in your own back yard, a solar battery that will supply your home with all the electricity you need.



INSTALLING A SOLAR BATTERY ON A TELEPHONE POLE

Chapter Fourteen

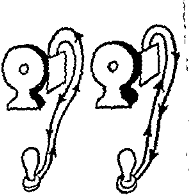
ALTERNATING-CURRENT ELECTRICITY



IT TAKES a very high voltage, or strong electric push, to make electricity flow long distances. As we said in the last chapter, electric power lines that stretch long distances between cities may require as much as 230,000 volts' pressure. After electricity at this high voltage arrives in a city, it must be cut down to a reasonable pressure for use in homes and factories. It would be very dangerous to try to use such high-voltage electricity in a house. The high electric pressure would push electricity through ordinary insulation and make it jump through the air for as much as a foot; people would be electrocuted and fires would start. Such high-voltage electricity would not be a servant in our homes, but a dangerous enemy.

To bring the voltage down to a safe range, *transformers* are used. But in order for transformers to work, they must be fed a special form of electricity. This special form of electricity, called "alternating current," or "AC," may seem very strange to you.

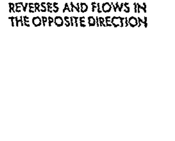
In a wire carrying alternating current, the electricity alternates in its direction of flow at rapid intervals. That is, it flows in one direction for a fraction of a second, then reverses and flows in the other direction. The change from one direction to the other and back again is called a "cycle." The alternating current we normally use does this sixty times a second, and is thus known as "60-cycle" alternating current. If you will look at the manufacturer's name plate on an A-C motor, you may find "60-cycle" stamped on it.



WITH ALTERNATING-CURRENT ELECTRICITY, THE ELECTRICITY FLOWS ONE WAY IN THE WIRES, THEN REVERSES AND FLOWS IN THE OPPOSITE DIRECTION

Why go to all the trouble of pushing the electrons in a wire in one direction and then in the opposite direction? Wouldn't it be simpler merely to start the electrons moving in one direction and then keep them moving?

Those were questions that advocates of alternating current had to answer, some fifty years ago, when they proposed the use of alternating current in place of the one-direction direct current. Their answer was simple. High voltage was needed to transport electricity long distances. Low voltage was needed for homes and factories. With alternating current, transformers could step up or step down the voltage as needed. Transformers have no moving parts, and they can handle much higher voltages than generators can efficiently produce.



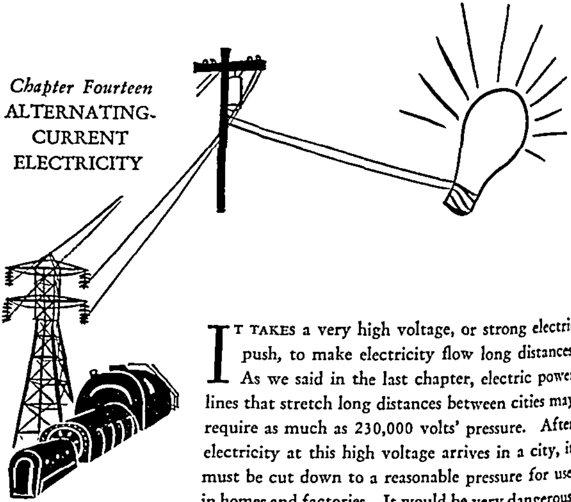
THE METAL BOXES ON ELECTRIC-LIGHT POLES ARE TRANSFORMERS

With direct current, however, no such simple device as a transformer would work to increase or decrease the voltage. To change the voltage of direct current, a motor-generator outfit is required.

Another advantage of alternating current is that

Chapter Fourteen

ALTERNATING-CURRENT ELECTRICITY



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The secondary coil has a flow of electrons induced in it by the constantly moving magnetism. The amount of electric push, or voltage, developed in the secondary coil depends on the number of turns of wire in the two coils. If the first, or primary, coil has 100 turns, and the secondary coil has 200 turns, or twice as many, then the voltage developed in the secondary will be twice that applied to the primary.



AS MAGNETISM MOVES OUT FROM FIRST COIL, CURRENT IS INDUCED IN SECONDARY COIL

This may be explained by saying that the magnetic "breeze" from the moving magnetism is acting on a wire twice as long as the primary wire. This magnetic "breeze" thus gets in a push that is twice as great; or, the voltage is twice that in the primary.



THEN, WHEN MAGNETISM MOVES BACK TOWARD THE FIRST COIL, CURRENT IS AGAIN INDUCED IN THE SECONDARY COIL

It works the other way, too. With more turns of wire in the primary, there will be less voltage in the secondary. Thus a transformer can be made that will change 110-volt AC to 550-volt AC. Or it can change the 550 to 110. Almost any combination of voltage can be arranged for, merely by changing the number of turns of wire in the two transformer windings.

The Ignition Coil

The ignition coil on an automobile is a small transformer. It transforms the 6 or 12 volts of the car battery to a high voltage, which may be as much as 20,000 volts. This high voltage then causes a spark at the spark plug inside the engine cylinder. The spark ignites the gasoline vapor in the cylinder.

A-C generators can be built in much larger sizes than D-C generators. For example, a single A-C generator might be able to supply enough electricity for a city of half a million people, while it would take at least 100 D-C generators to supply the same amount of electricity.

How the Transformer Works

The transformer works on the principle of magnetism. We can make a simple transformer by putting two coils of wire side by side. If we connect one coil to a source of alternating current, we will find that current will flow in the second coil, even though there is no connection between the two.

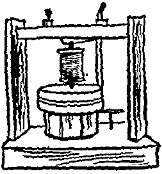
This is the reason why: There is a magnetic field around the first coil of wire only so long as current is flowing in the wire. But since alternating current is constantly changing direction, it is continually stopping and then starting again. This means that the magnetic field disappears and then reappears every time the current alternates, or changes direction. Consequently, the magnetic field is in constant *motion*. As the magnetic field appears, it moves outward from the coil. As it disappears, it moves in toward the coil. Magnetism is thus constantly moving through the second, or secondary, coil. Essentially, the action is no different from that in the generator, except that in the transformer the wires are stationary and the magnetism moves.



MAGNETISM SURROUNDS THE COIL WHEN ELECTRICITY FLOWS

the way our ears detect sound; that is, how we hear. We shall have more to say about this later in the chapter.

The stage was set, then, for Alexander Graham Bell, the great American inventor of the telephone. Volta, Ampère, and others had worked out laws covering the basic characteristics of electricity. Kelvin, Helmholtz, and others had explained how sound is produced and how we hear it. All that was needed was a man who could weave these two fields of knowledge together so that sound could be carried on wires. Bell was that man, and in 1876 his many years of hard labor and experimentation were crowned with success. The telephone was born.



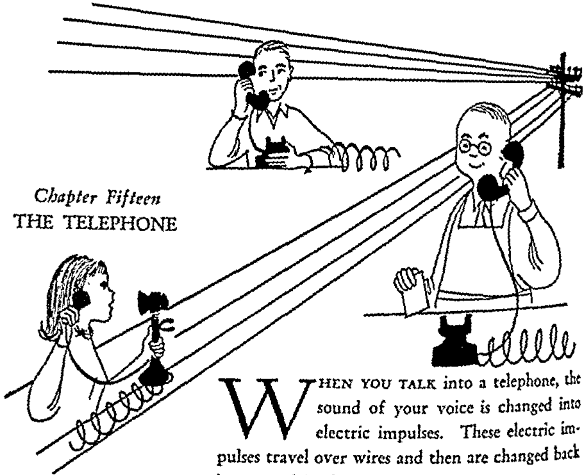
BELL'S FIRST TELEPHONE

More than that, his experiments and his success laid the foundations upon which other scientists could build. The inventors of the phonograph, radio, television, and other electronic devices owe Bell a debt, just as Bell himself was indebted to those scientists who came before him.



Sound

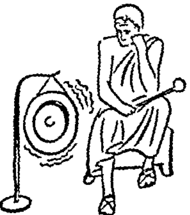
Before we explain the telephone, it may be well for us to describe what sound is and how we hear it. Picture yourself seated in a ball park, watching a baseball game. The pitcher winds up and delivers, and the batter connects and lines the ball out into left field for a hit. You hear the sharp "crack" of the bat connecting with the ball. What caused that sound and how did it get to your ear?



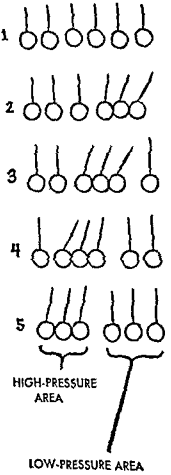
Chapter Fifteen
THE TELEPHONE

When you talk into a telephone, the sound of your voice is changed into electric impulses. These electric impulses travel over wires and then are changed back into sound in the receiver.

Men have thought about and experimented with sound for thousands of years, but only in the past hundred years or so has sound come to be reasonably well understood. Aristotle, a Greek philosopher who lived 2,300 years ago, made a brilliant guess about the nature of sound. He suggested that sound is caused by bodies striking the air so that the air contracts and expands. But little was done for many centuries to prove or disprove his theory. At last, in the nineteenth century, interest was revived and many men began to study and experiment with sound. G. S. Ohm, Lord Kelvin, H. von Helmholtz, and others worked out many of the basic laws of acoustics (the science of sound). In addition, Helmholtz proposed an explanation of



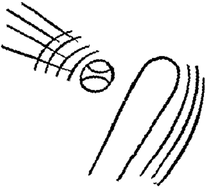
and your ear as a series of basketballs, hung on strings and several inches apart. The first basketball (or molecule) is pushed out from between the baseball and the bat as they come together. This first basketball then bumps the second, the second the third, and so on down the line. As this impulse travels forward, balls are momentarily bunched together, leaving behind a place in the line where they are relatively far apart. The space where they are bunched together is called a "high-pressure area"; the space where they are far apart is called a "low-pressure area."



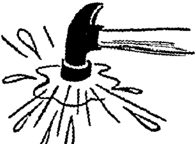
The terms "high pressure" and "low pressure" actually refer to the pressure in the air; for when the molecules of air are close together, the air pressure is high, just as packing many water-vapor molecules together in the steam-engine cylinder creates a high steam pressure. It is these high-pressure and low-pressure areas, moving in waves past our ear, that cause the eardrum to vibrate so that we "hear" sound. The high- and low-pressure areas move out from the source of sound at about 1,100 feet a second at ordinary temperatures. Thus, if you were a mile (5,280 feet) away from an explosion, it would be nearly 5 seconds before the sound waves reached you so that you would hear it.

How We Hear Sound

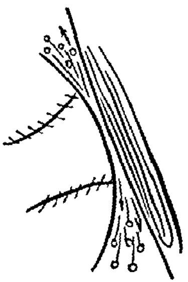
The human ear is a marvelous mechanism. The inner end of the ear channel is closed off with an eardrum—an elastic, skinlike diaphragm. Back of



Before we can answer that, we must know more about the air through which the sound traveled. The air is composed of atoms or molecules of different gases, such as nitrogen and oxygen. These molecules are in rapid motion, moving about in all directions, bumping into each other, and bounding off in new directions. There are billions of these molecules in every cubic inch of air.



When the bat hits the ball, the air between the two is driven out. *Let us take a supermicroscopic* look at this action. As the bat approaches the ball, the air between them is pushed out of the way. The last few molecules have to move very rapidly. You can get an idea of this action with a hammer and a puddle of water on a concrete sidewalk. If you hit the puddle with the hammer, water will be splashed quite a distance. The water is squeezed out from under the descending hammer head, so that it squirts out in all directions.



In much the same way, the air molecules between the bat and the ball are squeezed out as bat and ball connect. The high-speed movement of these molecules causes them to bump against molecules just ahead of them. These molecules then bump other molecules farther out, and the high speed is thus passed on from molecule to molecule in an ever-widening circle. Finally, the air molecules in our ears are bumped and they then bump our eardrums, so that our ears report to us that we have "heard" the crack of the bat hitting the ball.

It might help you to picture this if you consider the line of molecules between the ball and the bat

Mr. Bell's Reasoning



We can almost follow Alexander Graham Bell's line of reasoning point by point. Sound is a series of high-pressure and low-pressure waves moving through the air. When they pass our eardrums, the drums are set into motion. The motion is translated into nerve impulses that enter the brain to inform us we are hearing sound. Why couldn't a mechanical eardrum be made that would translate the sound impulses into electric impulses, that is, into surges of electricity? These electric impulses could be carried through a wire and then reconverted into sound by some sort of mechanical sounding device.

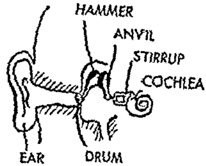


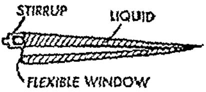
WHEN THE DIAPHRAGM IS PUSHED INWARD, MORE CURRENT CAN GET THROUGH

After much difficulty, Mr. Bell found his mechanical eardrum. It was made up of a small diaphragm behind which were packed many tiny grains of carbon. These grains of carbon had a certain amount of electric resistance and, if connected to an electric battery, would allow a certain definite amount of electric current (or number of electrons) to get through. But if the diaphragm were pushed inward, the grains of carbon would be crowded together so that there would be more points of contact between them. These additional points of contact then would allow more electrons (or electric current) to pass through. If the diaphragm were pulled outward, the grains of carbon would have more room and there would be fewer points of contact between grains, and so fewer electrons could flow through.

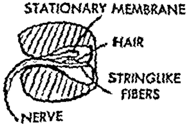


WHEN THE DIAPHRAGM MOVES OUT, LESS CURRENT CAN GET THROUGH





COCHLEA UNCOILED



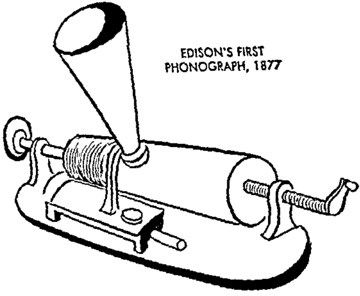
SECTIONAL VIEW OF COCHLEA

the drum are three tiny bones, hinged together. One of these bones is attached to the eardrum. Another of the bones is attached to the cochlea (kŏk′-lē-ăh), a hollow structure shaped something like a snail shell and partly filled with liquid.

When a high-pressure area moves past the ear, the eardrum is forced inward slightly. When a low-pressure area moves past, the drum is pulled outward slightly. This in-and-out movement, or vibration, of the eardrum, causes the three bones (the hammer, the anvil, and the stirrup) to move in unison, as they are hinged together. Their movement sets the end of the cochlea to vibrating, so that a ripple passes through the liquid inside the cochlea. Above this liquid is a series of tiny, stringlike fibers in which tiny hairs are set. The rippling of the liquid causes these fibers to sway, and then the hairs move back and forth under the stationary membrane.

If these hairs were outside, on your skin, you would say that something was tickling you. But because the hairs are inside your ear and are connected to a different part of your brain by the auditory, or ear, nerve, you interpret this "tickling" of hairs as a sound.

You can actually feel the vibrations of sound with your fingers. Hold a large sheet of paper tightly between your hands and close to your mouth. If you sing the scale loudly, you will feel a tickling in the fingers that grip the paper, as you sing certain notes. Those fingers are feeling, or "hearing," the sound.



Chapter Sixteen

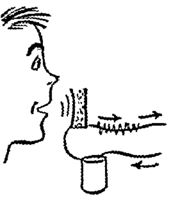
THE PHONOGRAPH

ALEXANDER Graham Bell had the idea that he could change sound impulses into electric impulses and then change the electric impulses back into sound impulses. With the invention of the telephone, he proved that this idea was practical.

Thomas Alva Edison, the great American inventor, had a different idea. Why couldn't the sound impulses be made to imprint their characteristics onto a soft plastic material? The record made in that way could then be played back at a later time, to reproduce the sound.

Basically this was a very simple idea, but many years of experimenting and work were needed before Edison's "talking machine" became a reality. The early talking machine looked very little like the phonographs or record players that we have today. Even the shape of the records has changed. The first records were shaped like cylinders. Modern records, as we all know, are flat.

This, then, is the telephone *transmitter*—the part that you talk into. When high- and low-pressure areas (or sound waves) strike the diaphragm it moves inward and outward, allowing first more and then less electric current to pass through. This means that the high- and low-pressure areas are converted into first strong and then weak electric impulses.



THE TRANSMITTER CHANGES THE HIGH- AND LOW-PRESSURE AREAS, OR SOUND, INTO ELECTRICAL IMPULSES

In the receiver, these electric impulses of varying current strength are converted back into sound. The receiver contains a thin iron plate, or diaphragm, under which there is a tiny coil of wire surrounding a magnet. The current from the transmitter passes through this coil of wire, causing the magnet to vary in strength. When the current is strong, the magnetism is strong; when the current is weak, the magnetism is weak. The iron diaphragm is pulled inward when the magnetism is strong, moves outward as the magnetism weakens.

Thus, as the amount of current varies (in obedience to the movement of the transmitter diaphragm), the receiver diaphragm moves in and out. This causes the receiver diaphragm to bump air molecules and set them into motion in high- and low-pressure areas. These high- and low-pressure areas are reasonable copies of the high- and low-pressure areas (or sound) that are vibrating the transmitter diaphragm. When you say, "Hello" into a telephone transmitter, the diaphragm in the receiver at the other end of the line will vibrate and give off a "Hello."

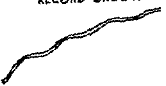


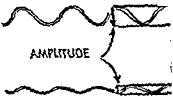
THE VARYING ELECTRICAL IMPULSES MOVE THE RECEIVER DIAPHRAGM IN AND OUT TO REPRODUCE SOUND

"the," and "lip" out loud, to see how your tongue and lips change your "Ahhhh" into words.

Making a Record

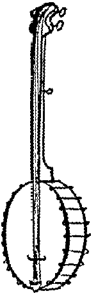
Early record makers, or recorders, used a sort of mechanical "eardrum," which vibrated to any sound. A sharp needle was pivoted to the center of the "eardrum," or diaphragm, so that the end of the needle would move back and forth as the diaphragm vibrated. The record, made of a plastic material, was laid on a turn table and the end of the needle was placed on it. When the record revolved, the needle cut a groove in it. The needle moved inward toward the center of the record as the record continued to revolve, so the groove spiraled in toward the center of the record.





Any sound that was made caused the diaphragm to vibrate, and this vibration, in turn, caused the end of the needle to move back and forth slightly. Consequently, the groove cut was not uniform, but was slightly irregular, or wavy, in shape.

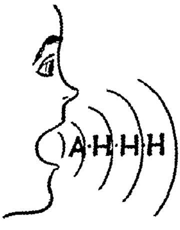
If we were to look closely at one of the grooves in a record, we could see the waviness of the grooves. When a loud sound has been recorded, the waviness is more pronounced than when a soft sound has been recorded. This is because the air molecules bump each other harder when the sound is loud; then they bump the diaphragm harder and make the needle move through a wider range, or greater *amplitude*. Thus the amplitude of the waves, or



Before we can understand just how a phonograph record is made, we need to know some additional things about sound. We learned in the previous chapter that sound is a series of high- and low-pressure areas, or waves, moving through the air. If we pluck a string of a banjo or any other stringed musical instrument, we hear a sound. This sound is caused by the vibration of the string —that is, the string is flipping back and forth very rapidly, as we can see by looking closely at it. The vibration of the string repeatedly bumps air molecules, thus causing the high- and low-pressure areas to move out from the string to our ears.



If you haven't any stringed instrument handy, stretch a rubber band between your hands and pluck it with your thumb. It will give off a somewhat musical note, and you can see it vibrating as the note is sounding.

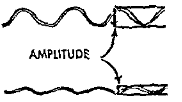


When you say, "Ahhhh," that sound is caused by the vibration of "strings" in your throat. These strings, which are called "vocal cords," are set into vibration by air rushing out from your lungs. That is, when you sound your "Ahhhh," certain throat muscles are directing the air past these vocal cords. You can set the strings of any stringed musical instrument vibrating by blowing on them. In your throat, as the vocal cords are set to vibrating, they bump air molecules to produce the "Ahhhh." You form this sound into speech by moving your tongue and lips in such a way as to cut off or change the character of the sound. Say the words "papa,"

"the," and "lip" out loud, to see how your tongue and lips change your "Ahhhh" into words.

CLOSE-UP OF A RECORD GROOVE





Making a Record

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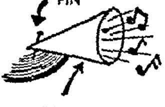
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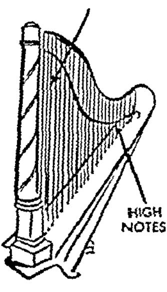


the distance between the top and the bottom of a wave, is determined by the loudness of the sound. High amplitude means a loud sound; low amplitude means a soft sound.

When the record is put into a record player, a needle follows the groove as the record revolves. In early record players, the needle was pivoted to a diaphragm in much the same way as in the recorder. The rapid vibration of the needle end as it followed the waves in the groove made the diaphragm vibrate. This vibration of the diaphragm, bumping air molecules, reproduced the original sounds that had caused the waviness in the grooves when the record was cut. When the original sound was loud, the amplitude of the waves was large and the record-player needle and diaphragm would vibrate harder, to produce a louder sound.



You can feel and hear these vibrations by rolling up a sheet of paper into a cone and sticking a pin through the end of the cone. Put the point of the pin into a groove of a record that is revolving in a record player. You will feel a tingling in your fingers as they hold the cone. And you will hear the sound, too.



One other matter we must think about, and that is the *pitch* of the sound. If you pluck one of the short strings of a harp, you will hear a high-pitched note; if you pluck one of the long strings, you will hear a low-pitched note. The difference between the two lies in the speed with which the string vibrates. The short string vibrates more rapidly; that is, it swings back and forth more quickly, and thus

bumps the air molecules more often. One of the middle strings can be made to vibrate 256 times a second (this is middle C). This means that it swings one way and then back 256 times each second.



HIGH NOTE



LOW NOTE

What does that mean in terms of the waves that are cut in the record groove? If we could look closely at a groove, we would see that the peaks of the waves are close together when a high-pitched note has been recorded, and that they are far apart when a low-pitched note has been recorded.

If the sound of a string that vibrates 256 times a second is cut into a record groove, we find that 256 waves are made each second. By higher-pitched notes, more waves per second would be made; by lower-pitched notes, fewer waves per second. The number of waves per second is called the *frequency*. In the case of high-pitched notes, the waves occur more frequently and consequently the waves have a *high frequency*. Low-frequency waves produce low notes.

Thus, in our investigation of how the phonograph operates, we have come across two important characteristics of sound waves: *amplitude* and *frequency*. Amplitude determines loudness; frequency determines pitch.

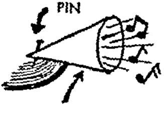
Making Duplicate Records

After a record is made in the recorder, thousands of duplicates can be produced. These duplicates are the ones that you buy at a record shop and take home to play on your own phonograph. The

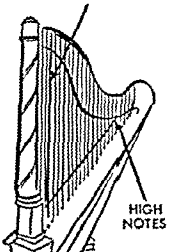


the distance between the top and the bottom of a wave, is determined by the loudness of the sound. *High amplitude* means a loud sound; *low amplitude* means a soft sound.

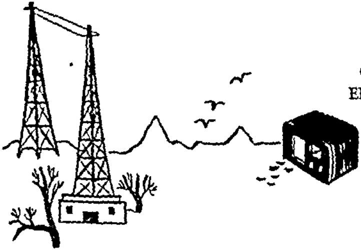
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Chapter Seventeen

ELECTRON TUBES

AFTER BELL discovered how to send sound from one place to another over wires, the next step was to find some way to send sound between distant places *without* wires. In England, this sort of communication is called "wireless"; we call it "radio." Radio, as we know it, is less than fifty years old. Even so, many of the basic principles of sound and electricity that are utilized in radio have been known for hundreds of years.

Franklin, Volta, Ampère, and others made essential electrical discoveries. Ohm, Helmholtz, Bell, and other men did important work with sound. Then, in 1883, Thomas Alva Edison discovered a peculiar action in one of his early electric-light bulbs. A generation later this action was to be known as the *Edison effect*. The operation of our modern radio sets is based upon this effect.

Edison had invented his electric-light bulb shortly before, but the filaments were not satisfactory be-

duplicates are made by first preparing a mold, or form, which copies, in reverse, the grooves in the original record. This mold can then be used to press out in plastic as many duplicates of the original record as are needed.

Modern Electric Phonographs

CRYSTALS



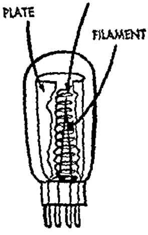
Modern electric phonographs, or record players, make use of electron tubes (such as radio tubes), so we shall have to wait before explaining them until we have discussed radio, in the next chapter.

However, the record player still uses a needle that follows the groove in the record; only here, the vibration of the needle is not converted directly into sound but into electrical impulses, in much the same way as vibrations are in the telephone. In many record players the needle is mechanically connected to a special type of crystal. Crystals are very common, since many chemical compounds form crystals. Water crystallizes into snow or ice. Sugar and salt are crystals. Record players make use of crystals of Rochelle (rō-shel') salts.

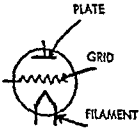
These crystals have a very interesting property. When they are squeezed and released, they generate tiny currents of electricity. Thus, when the record-player crystal has varying amounts of pressure put upon it as the needle moves back and forth, varying amounts of electricity flow from it. The varying electrical flow then goes through electronic circuits (including radio tubes) and finally causes the loudspeaker diaphragm to vibrate, as explained in the next chapter.

Fleming, made use of the Edison effect as he created the first working electron tube. It was crude compared with later ones, but it found practical use in the early radio sets with which men were experimenting at that time.

Then, in 1906, Dr. Lee De Forest, an American, added a third part to the electron tube. This third part he named the *grid*, and the tube was known as a *three-element* tube, or a triode. The elements were filament, plate, and grid. The addition of the grid made the electron tube far more useful, for the grid could very quickly change the number of electrons flowing between the filament and the plate. It could let many flow, and then cut off the flow almost instantly. As we shall find, this is an exceedingly important activity of the electron tubes used in radios. Such tubes are often called "vacuum tubes," since the air is removed from them so that there is a vacuum inside them.



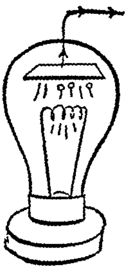
DE FOREST'S TRIODE



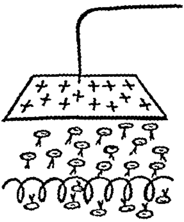
SYMBOL FOR TRIODE

How the Grid Works

Suppose that we have a very weak signal coming in over a telephone line. The electric impulses (or signal), which have traveled a long way, are not strong enough to cause the diaphragm in the telephone receiver to vibrate enough to be noticed. You will remember that the receiver works on variations of electric-current strength, which cause variations in magnetic strength around the coil of wire in the receiver. These variations of magnetic



cause they did not last very long. To analyze this shortness of filament life, Edison sealed a metal plate into the top of the glass bulb of a light, connected an electric battery to the plate, and turned on the light. To his surprise, he noticed that electric current was passing from the filament to the plate, *across empty space.* In other words, electricity was moving between the filament and the plate, even though there was no electrical connection, or wire, between them.



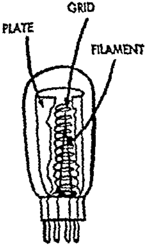
This is what was happening: The light filament was crowded with electrons; electric current was passing through it. The metal plate was connected to the positive terminal of the electric battery. The filament, therefore, had many more electrons than the plate had. You will recall that like electric charges repel each other, while opposing electric charges attract each other. In other words, the many negatively charged electrons in the filament were pushing against each other, while the positively charged plate was attracting them. As a result, many of the electrons left the filament to fly through space to the plate; that is, electric current passed from the filament to the plate.

Fleming and De Forest

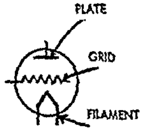
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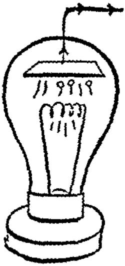
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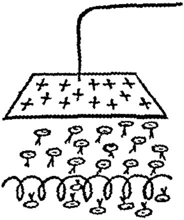
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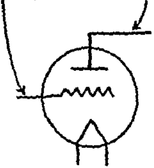
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Fleming and De Forest

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dred grid electrons manage to repel all but the thousand electrons. However, when the number of electrons on the grid drops to only 10, many more electrons can get through. As many as 2,000,000 electrons can get through each second in some types of electron tube. Thus the incoming signal, varying between 10 and 100 electrons a second, is amplified by the tube until it varies from 1,000 to 2,000,000 a second. Now, what do we have? The incoming signal is weak; it can put onto the grid only from 10 to 100 electrons. But the outgoing signal is strong; as many as 1,000 to 2,000,000 electrons a second flow from the filament to the plate. They then flow through the receiver. The signal is now strong enough to vibrate the diaphragm so we can hear sound. If the signal is still not great enough, a second tube can be used to produce further amplification.

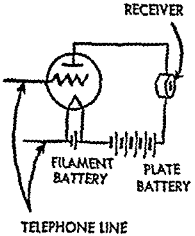
10 TO 100 ELECTRONS COMING IN EACH SECOND HERE MEAN 1,000 TO AS MANY AS 2,000,000 ELECTRONS A SECOND LEAVING HERE



Electron tubes can be used to step up the signal coming in from an electric-phonograph crystal. That is, the variations in electric current are made great enough to vibrate the diaphragm of the phonograph loudspeaker. The construction of the loudspeaker is very much like that of the telephone receiver. It contains a coil of wire, through which the current passes. As the strength of the current changes, the magnetic field changes, causing the diaphragm to move, or vibrate, and so to produce sound.



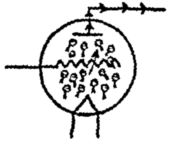
A SECOND TUBE GIVES FURTHER AMPLIFICATION



strength cause the diaphragm to vibrate so that sound is produced. However, if the incoming signal is weak, the variations will not be great enough to cause the diaphragm to vibrate sufficiently for us to hear any sound.

A three-element electron tube can be used to amplify, or increase the strength of, the electric impulses so that the vibrations of the diaphragm will be strengthened. This is done by connecting the telephone line to the grid of the electron tube. If no current were coming in on the line, the grid would have no excess electrons on it. Consequently, large numbers of electrons would flow from the filament to the plate. However, if current were coming into the grid from the telephone line, there would be numerous electrons on the grid. Now electrons trying to go from the filament to the plate would be repelled. They would not be able to get to the plate. Electrons, you will recall, repel each other, or push each other away when they come close together. Thus, as the electrons leave the filament and start toward the plate, they approach the grid; the electrons on the grid repel them. They cannot get through.

NO CURRENT TO GRID, MANY ELECTRONS FLOW TO PLATE

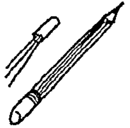


ELECTRONS ON GRID REPEL ELECTRONS FROM FILAMENT. FEW ELECTRONS FLOW TO PLATE

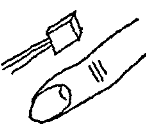


It does not require very many electrons on the grid to produce this effect. Let us think about a simple example. Suppose that the variation in current coming in puts from 10 to 100 electrons on the grid. With 100 electrons on the grid, suppose that only 1,000 electrons can flow from the filament to the plate every second. That is, the hun-

Scientists, realizing this and other drawbacks of electron tubes, searched for other ways of doing the jobs that electron tubes do. Then, just a few years ago, a new device, the *transistor*, was announced by Bell Telephone Laboratories. After years of work two Bell scientists, Brattain and Bardeen, were able to show to the world, in 1948, one of the first of these remarkable devices.



It did not look very impressive. In fact, it was so small that you had to look carefully to see it. For many transistors are smaller than the eraser on the end of a lead pencil. Yet some transistors can replace electron tubes hundreds of times their size! Transistors need far less current, and produce far less heat, than comparable electron tubes.



But what are transistors? And how do they work?

Transistors are made of small slices of germanium crystals. Germanium is an element, just as copper and oxygen and hydrogen are elements. It is crystalline in form. The slice of germanium crystal used in a typical transistor may be less than ⅛ inch square and less than 1/32 inch thick. Look at a ruler to see how small this is.

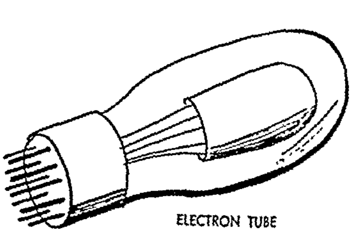


In one kind of transistor, three wires are fastened to the crystal of germanium. Let us imagine that we are using this transistor to amplify a telephone signal. The hookup would be about as shown on the next page.

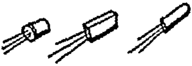
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Chapter Eighteen

TRANSISTORS



ELECTRON TUBE

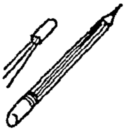


TRANSISTORS

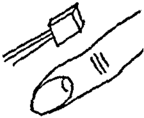
ELECTRON TUBES are wonderful devices. Besides their indispensable use in radios and television sets, they do many other jobs. They are used in radar and motion-picture equipment, they control manufacturing processes, and they are basic in "electronic brains" such as the UNIVAC. We shall find out more about these in later pages of the book.

But vacuum tubes have a few drawbacks. For one thing, they waste a good deal of electricity. One of the elements in a vacuum tube must be heated so that it will give off electrons. This heating requires electricity and produces unwanted heat. You probably know from experience that the inside of a radio gets quite warm. Imagine how much heat is produced by the hundreds of vacuum tubes in the electronic controls of a supersonic jet airplane! Such planes have to use special cooling equipment to help get rid of the heat.

Scientists, realizing this and other drawbacks of electron tubes, searched for other ways of doing the jobs that electron tubes do. Then, just a few years ago, a new device, the *transistor*, was announced by Bell Telephone Laboratories. After years of work two Bell scientists, Brattain and Bardeen, were able to show to the world, in 1948, one of the first of these remarkable devices.



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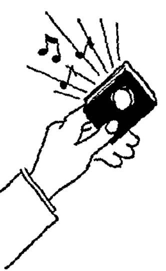
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through a battery to wires *B* and *C*. With no signal, no current would flow from the battery through the receiver. But when a signal comes in, the transistor amplifies it in the following way. The signal consists of surges of electrons, or electric current, as explained on page 64. The electrons enter at wire *B* and leave at wire *A*. As electrons move out of the germanium, they leave behind germanium atoms with positive charges (that is, some of the atoms lose electrons). Some of these positive charges are then satisfied by electrons flowing in from wire *B*. But other positive charges are satisfied by electrons coming in through wire C.

Here is the way to think of the actions taking place in the germanium. Positive charges are produced in the crystal around wire *A*. These positive charges can be thought of as *holes*, since they are an *absence* of electrons. When a signal comes in on wires *A* and *B*, many "holes" are produced in the germanium. Electrons then flow in from wire *C* to fill these "holes"; that is, current flows between wires *C* and *B*. This current causes the receiver to operate.



The amazing thing about all this is that a very small current, or signal, coming in on wires *A* and *B* produces many "holes," and thus a large current in the germanium, between wires C and *B*. In other words, the signal is greatly magnified. This is the same job the electron tube does (see pages 94 to 97.



There are other types of transistor in use, and still more are being developed in laboratories. Already you can buy tiny radios that use transistors instead of electron tubes. Television sets and many other types of electronic equipment are using, or soon will be using, transistors instead of electron tubes. With transistors all this equipment can be made much smaller.

One remarkable use for transistors is in hearing aids. People who are hard of hearing wear special devices that amplify sound so that they can hear. These amplifiers have long been made with tiny electron tubes. But still smaller hearing aids, using transistors, are now being built into horn-rimmed glasses. When you put these on, one of the elbows that fit over the ears carries the amplified sound to the bone above the ear. From there it passes through the bone to the inner ear. Chapter 15 describes the ears and how they work.

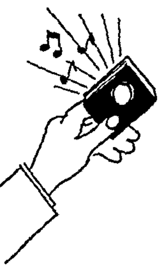


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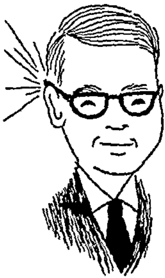
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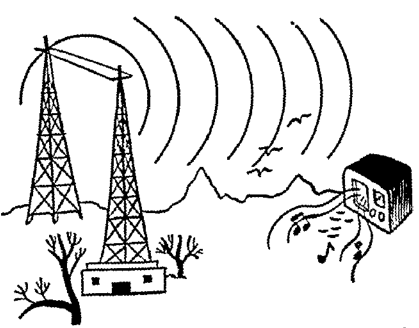
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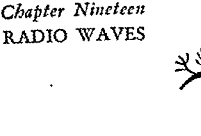
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Chapter Nineteen
RADIO WAVES

BEFORE WE ASK how radio, or electron, tubes work in an actual radio set, let us first find out how radio signals get from the broadcasting station to your receiver. We know that sound signals travel through the air in waves of high pressure and low pressure. In a somewhat similar way radio signals travel in waves of magnetism.

Magnetism, you remember, is produced when electrons flow through a wire. Such magnetism, because it is electrically produced, is called electromagnetism (ē-lĕk'trō-măg'nĕ-tĭz'm). The heavier the electric current, the stronger is the electromagnetism.

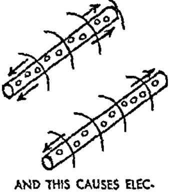


ELECTRONS FLOWING IN A WIRE PRODUCE ELECTROMAGNETISM

In a transformer, current alternates, or repeatedly changes direction, in the primary winding. This causes waves of electromagnetism to move out from the winding, and these waves, cutting across the secondary winding, cause electrons (or current) to flow in the secondary winding.

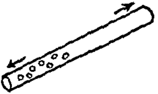
In very nearly the same way, the radio broadcasting station sends out electromagnetic waves that induce electron movement in the radio receiver. This electron movement then results in sound, so that you can hear whatever program the radio station is broadcasting. One of the remarkable things about it is that the electromagnetic waves can move through great distances.

ELECTRONS RUSH BACK AND FORTH IN BROADCASTING ANTENNA



AND THIS CAUSES ELECTRONS TO RUSH BACK AND FORTH IN RECEIVING ANTENNA

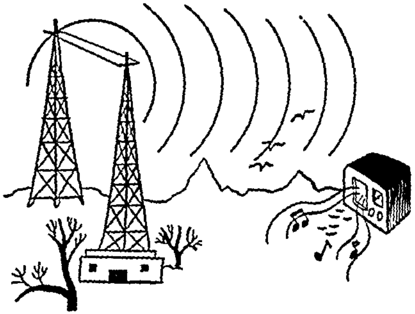
At the broadcasting station, the antenna (ăn-tĕn'ah) provides the starting point for the electromagnetic waves. The antenna is either a long wire or a high tower. The broadcasting equipment forces electrons to rush back and forth in the antenna at very high speed. This is *alternating current*, but it alternates much more rapidly than the AC we use in our homes. For when the radio announcer says, "This is station XYZ broadcasting on a frequency of 760 kilocycles" (kĭl'ō-sī'k'ls), he means that the current is moving in the antenna in one direction, stopping, and then going in the opposite direction 760,000 times every second! "Kilo" (kĭ'lō) means 1,000; therefore, 760 kilocycles means 760,000 cycles.



760 KILOCYCLES MEAN ELECTRONS MOVE IN ONE DIRECTION, THEN IN THE OTHER DIRECTION 760-000 TIMES A SECOND

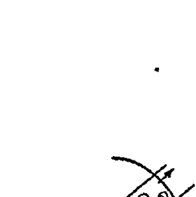
Do you recall what we said back on page 78 about the transformer? In the transformer, alternating current in a coil of wire causes a changing magnetic field around the coil. In the same way, alternating current in the antenna causes a changing magnetic field around the antenna. This changing magnetic field travels out in all directions from the antenna at tremendous speed. Since the magnetic field is

Chapter Nineteen
RADIO WAVES



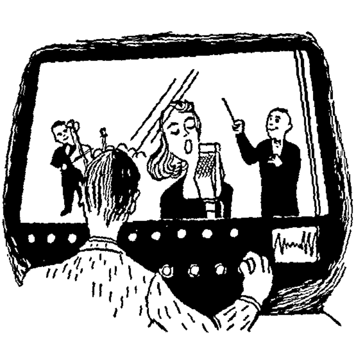
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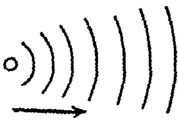


Chapter Twenty

RADIO BROADCASTING AND RECEPTION

At the broadcasting station, the *microphone* changes sound into electrical impulses. The microphone, you see, acts much like a telephone transmitter. The electric impulses coming from the microphone are amplified by electron tubes, but something further must be done to them before they can be sent to the broadcasting antenna: they must be mixed in with the high-frequency alternating current that passes back and forth in the antenna. This high-frequency alternating current produces the high-frequency radio waves mentioned in the previous chapter. These waves are called the *carrier* waves, because they carry the signals from the microphone with them as they move out from the antenna. The carrier waves are changed, or *modulated*, by the signals coming from the microphone. This modulation is what the radio receiver utilizes to reproduce the radio program from the broadcasting station.

THIS WAVE REPRESENTS THE BACK-AND-FORTH MOVEMENT OF 1,000,000 ELECTRONS IN THE ANTENNA. THESE ELECTRONS PRODUCE THE RADIO CARRIER WAVES



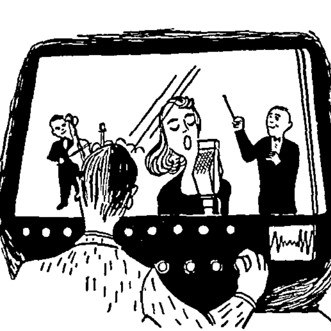
RADIO WAVES TRAVEL AT 186,000 MILES A SECOND

constantly changing, it moves out in waves; these waves are called radio waves. Radio waves travel with a speed of 186,000 miles a second.

These radio waves, or waves of magnetism, as they move out from the broadcasting antenna, cut through the antenna of your receiving set. This causes tiny currents of electricity to alternate in the receiving antenna. It is much the same as the transformer, in which alternating current in the primary winding creates waves of magnetism, and these electromagnetic waves then induce current in the secondary winding of the transformer. The broadcasting antenna is the primary and the receiver antenna is the secondary.

The tiny electric currents induced in the receiving antenna are very small. They may be compared to the weak signal coming in over a long-distance telephone line. You remember that this extremely weak signal is stepped up, or amplified, by electron tubes until strong enough to vibrate the telephone-receiver diaphragm so that sound is produced.

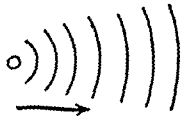
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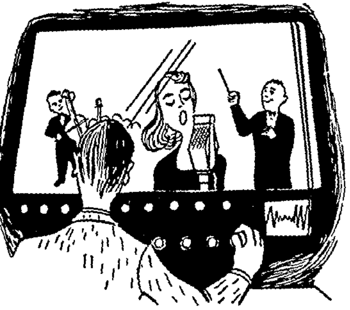
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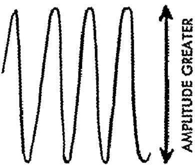


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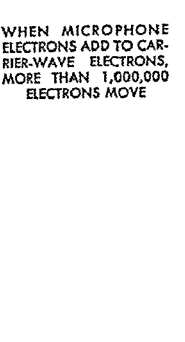


WHEN MICROPHONE ELECTRONS ADD TO CARRIER-WAVE ELECTRONS, MORE THAN 1,000,000 ELECTRONS MOVE

Let us see how the modulation takes place. The broadcasting equipment sends electrons surging through the antenna in one direction and then in the other. Suppose, for example, that when no electric impulses are coming from the microphone (meaning no sound is being made), there are one million electrons moving first one way and then the other in the antenna. In a radio station broadcasting on a frequency of 760 kilocycles, these electrons would be moving one way and then the other 760,000 times a second. These moving electrons are producing carrier waves.

If this electron movement is modified (or modulated) by having the electric impulses from the microphone mixed with them, an interesting thing will happen. For when a sound is made and then changed into electric impulses by the microphone, considerably more than a million electrons will move in the antenna. In other words, the microphone electric impulses (or electrons) add to the carrier-wave electrons.

This makes a stronger electron surge in the antenna and thus a stronger electromagnetic, or radio, wave. This particular wave, as it cuts through the antenna of a receiving set, will cause a flow of electrons in the receiver antenna that is stronger than the flow caused by the carrier wave alone.



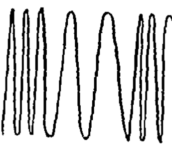
VARIATIONS IN THE NUMBER OF MICROPHONE ELECTRONS MODULATES THE WAVES

Thus variations in sound at the microphone cause variations in the strength, or *amplitude*, of the radio carrier waves. These amplitude variations cause variations in the number of electrons flowing in the

receiver antenna. The receiver then uses these variations to reproduce the sound that is made before the broadcasting-station microphone. The way in which this is done will be described below.

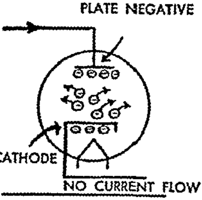
This system of modifying the carrier waves is called "Amplitude Modulation," or "AM." Until a short time ago, practically all radio sets worked on this principle. There is one fault to be found with AM sets: they pick up static, a popping or crackling noise that sometimes makes radio reception very poor. Static is caused by lightning or by certain electrical machines that give off electromagnetic waves. These waves, which are much like the waves from a broadcasting station, are picked up by the receiver. During electrical storms, the static may be so bad that no radio programs can be heard at all.

To reduce static trouble, a somewhat different sort of radio-wave modulation was adopted, and new broadcasting stations and many late-model radio receivers are being built to work on this different principle. The sort of wave modulation used is called "Frequency Modulation," or "FM." In FM radio, the mixing of the microphone electric impulses with the carrier-wave electrons causes the frequency of the cycles to vary. The microphone electric impulses (or electrons) cause the carrier-wave electrons to move back and forth at slower or faster rates. The waves remain of the same strength; that is, their amplitude does not change. However, the frequency with which the cycles

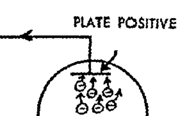


FREQUENCY MODULATION OR FM CHANGES THE FREQUENCY AT WHICH ELECTRONS MOVE BACK AND FORTH IN THE ANTENNA. THE NUMBER OF ELECTRONS IN MOTION STAYS ABOUT THE SAME

occur does change, and this is due to the modulating effect of the microphone electric impulses. Frequency modulation does not allow static to creep in, because the carrier waves vary through a wide range of frequencies, while the static waves cannot follow this variation of frequencies.



WHEN SIGNAL ELECTRONS MOVE INTO PLATE, THEY PREVENT CATHODE ELECTRONS FROM REACHING THE PLATE



BUT WHEN SIGNAL ELECTRONS MOVE IN OTHER DIRECTION, CATHODE ELECTRONS REACH THE PLATE

The Demodulator Tube

After the electrons are set to alternating in the receiver antenna, their back-and-forth movement (called the "signal") is utilized to produce sound. The first step in this process is to amplify the signal. This is done by connecting the antenna to the grid of an electron tube. We have already explained how a tube can amplify an incoming signal.

The much-strengthened signal is taken to a *demodulator* tube which "strains out," or eliminates, the high-frequency carrier waves. What remains of the signal then consists of electric impulses, or a varying flow of electrons, that correspond to the microphone electric impulses at the broadcasting station.

Let us see how the demodulator tube works. The tube contains a plate, a heating filament, and a cathode. When the cathode is heated, it gives off electrons. These electrons can move to the plate when the plate is positive, but if the plate is negative, the electrons will be repulsed. In other words, current will flow through the tube when the plate is positive, but no current can flow when the plate is negative.

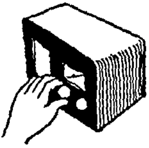
The plate is made to become positive and negative by bringing to it the signal from the antenna after this signal has been strengthened by amplifying tubes. This signal, consisting of electrons rapidly surging back and forth, causes the plate to change repeatedly from positive to negative and back again. The tube thus permits a series of current impulses to flow through it from the cathode to the plate.

The strength of these current impulses varies according to the amount of modulation produced by the microphone electric impulses at the broadcasting station. The current impulses thus correspond to those microphone electric impulses. If they are strengthened by additional amplifying tubes, and then are passed through the radio loudspeaker, they will cause the speaker diaphragm to vibrate so that the sound of the broadcast program is reproduced.

In FM sets, the demodulator tube operates on variations in the *frequency* of the radio waves, rather than on their amplitude. So far as the basic operation of the tube is concerned, however, there is no difference.

Tuning

When you tune a radio set, you select some particular station. What you do by turning the knob is to place your set into *resonance* with the broadcasting station. This might be compared to what happens when the G string of a violin is plucked when another violin is nearby. The G string of the second violin will also vibrate and give off sound,

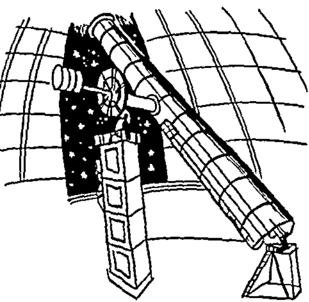


TUNING CHANGES THE ELECTRON PATH IN THE RECEIVER

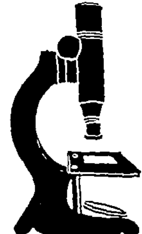
provided that the two violins are *in tune.* What happens is that the string on the first violin sends out sound waves of the right length and frequency to set the string of the second violin to vibrating.

In the radio set, what actually happens is that turning the tuning knob lengthens or shortens the electron path inside the radio. The various radio stations near the receiver all cause electrons to move back and forth in the receiver antenna. Because each station is broadcasting on a different frequency, the electrons are moving back and forth at different frequencies. When you tune a radio, you adjust the length of the electron path in the radio so that it can "receive" electrons moving back and forth at only one particular frequency. In other words, you tune in one station and thus tune out all others.





Chapter Twenty-one
LIGHT



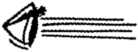
It is small wonder that light has been one of the most interesting things in the world to thoughtful men, for we are all conscious of light. We miss it very much when there is no light, because then we can see nothing at all. But when there is light, our eyes can report to us the shapes, sizes, and colors of everything in the world around us.

Light streams from distant stars across vast space to this earth of ours, and the lenses and mirrors in the telescopes and other intricate instruments of astronomers report to us the size, speed of motion, distance, and even the chemical composition of those distant stars. In a microscope, on the other hand, light is bent, or refracted, through a series of lenses so that the world of infinitely small things, like bacteria, is magnified into visibility. Light reflected from the pages of this book you are read-



ing carries to your eyes images of the words on the pages. When your brain interprets the images, the book makes "sense" to you.

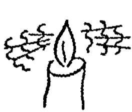
LIGHT



RAYS FROM EYE?



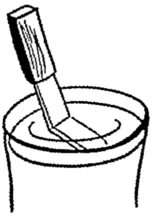
CORPUSCLES?



VIBRATIONS?

What is this strange thing, light, that helps us in these many ways to understand the universe in which we live? Some men of many centuries ago thought of light as a series of rays that shot out from our eyes. These rays were supposed to have been drawn out of our eyes by the heat or by some other property of the source of light. Later, other men suggested that light was a series of tiny particles, or corpuscles (kôr′pŭs-'ls), that were speeding out from the light source. Still another idea was that light was a vibratory activity—the space between the light source and our eyes vibrated in such a way that the sensation of light traveled to our eyes. However, as we shall find, light is a series of midget electromagnetic waves—very much like radio waves, except that they are much smaller.

Background



Claudius Ptolemy (tŏl′ĕ-mĭ), an Egyptian scientist who lived in Alexandria in the second century after Christ, made some of the earliest known experiments with light. He noted that light seems to bend as it passes through water or glass. You can see this for yourself by putting a knife into a glass filled with water. The knife actually seems to be bent when you look at it from a certain angle. You know that the knife is not bent, and so you can be sure that the light itself is bent. But Ptolemy did more than observe this curious fact. He

worked out some general rules about the manner in which light acts.

Then, in the twelfth century, the Arabian scientist Alhazen contributed a considerable amount of information on light, even going so far as to propose an explanation of how we see; that is, how our eyes function. A few decades later, in 1276, Roger Bacon, an Englishman, wrote a remarkable document, *Opus Majus* (ōp'ŭs mā'jus), which described how glass lenses could be used to magnify distant objects. But more than three hundred years were to pass before this knowledge was put to practical use, for it was not until about 1600 that Galileo (găl-ĭ-lē'ō), the Italian astronomer, built his first telescope. And almost another hundred years went by before Anton van Leeuwenhoek (vahn lā'vĕn-hook'), a Dutchman, built his first microscope.

GALILEO



Meantime, other men were trying to understand how light could travel from one place to another. Sir Isaac Newton, the English scientist, about 1700 proposed the corpuscular theory of light, by which he meant that light consists of tiny particles that stream out from the light source. Christian Huygens, the Dutchman, proposed almost at the same time that light travels by vibrations through space.



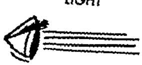
LEEUWENHOEK

What Light Is

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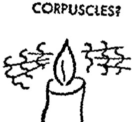
LIGHT



RAYS FROM EYE?



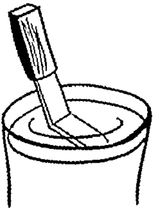
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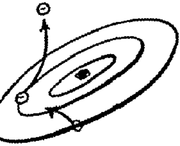


LEEUWENHOEK

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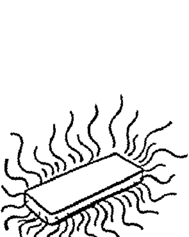
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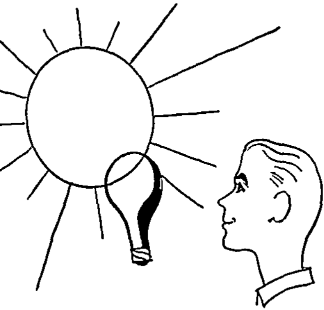
ORBIT HOPPING OF ELECTRONS IN AN ATOM PRODUCE LIGHT

Radio waves, we learned in an earlier chapter, are produced by the rapid motion of electrons alternating in an antenna. In a somewhat similar way, light is also produced by electron motion. However, this electron motion is *inside* the atom itself. For example, suppose that a piece of iron is heated until it is white-hot. It gives off a strong light. You will remember that when an object is heated, the atoms composing that object are set into faster and faster motion. As these atoms move faster and faster, so do their electrons whirl more and more rapidly about the atomic nuclei. Presently a peculiar thing happens: an electron in one of the inner orbits gets an extra burst of speed and flies out of its orbit. Almost instantly another electron from an outer orbit flies inward to fill the inner orbit.



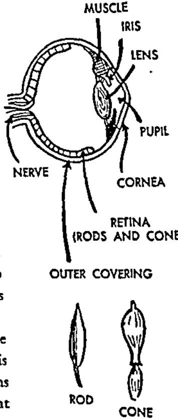
MANY ELECTRONS ARE ORBIT HOPPING IN A PIECE OF WHITE-HOT IRON

This orbit hopping is accomplished very quickly. The electrons move across the short distances at high speed; and, as we know, when electrons move, electromagnetic waves are produced. But the waves are very short, because the distance the electrons move between orbits is very short. We cannot see a single wave. In white-hot iron, however, many electrons are orbit hopping; thus many waves leave the iron. Our eyes "see" these waves as light.



Chapter Twenty-two

HOW WE SEE LIGHT

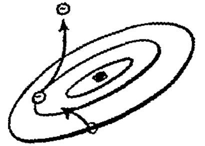


IN THE EAR, sound waves produce movement of a membrane that "tickles" certain fine hairs, and the brain interprets this "tickling" as sound. Likewise, in the eye, light waves "tickle" certain tiny nerve endings shaped like rods and cones, and the nerve impulses thus produced are interpreted by the brain as sight.

The back of the eyeball, called the "retina," is covered with millions of the tiny rods and cones that are sensitive to light. They all work together to inform the brain about the size, shape, and color of the object being seen. But in order for them to do this, they must be lighted with a clear, sharp image of the object. The *lens* of the eye performs the job of producing the sharp image.

The lens is made of a transparent and flexible membrane filled with a watery substance. It is suspended from a circular muscle, which performs the work of *focusing* the lens in such a way that

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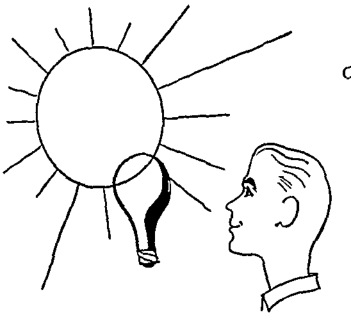


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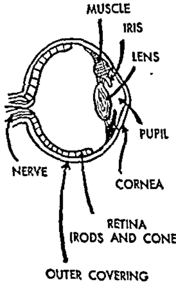
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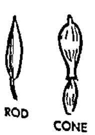


Chapter Twenty-two

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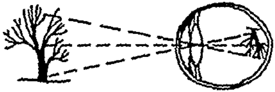
a sharp image will be thrown on the retina.

A telescope or a microscope is focused by moving the lens until the image sharpens so that it can be seen clearly. You yourself can do a bit of focusing with a round magnifying glass, or reading glass, which is a lens formed of glass. Stand across the room from a reading lamp that is turned on and hold the glass several feet from the wall. Move the glass toward the wall slowly until an image of the reading lamp comes into focus on the wall. You will notice that the image is upside down—the image made by a single lens is always inverted.

SEEING A DISTANT OBJECT THE LENS IS THIN

SEEING A CLOSE-UP OBJECT THE LENS IS THICK

The lens muscle in the eye produces focusing in about the same way. In this case, however, focusing is done by either thickening or thinning the lens. When the lens is thicker, the light waves, or light rays, going through are bent more. When the lens is thinner, they are bent less. This is important, since the lens can thus accommodate itself to either distant or nearby objects. For example, suppose that you are looking at a distant dot of light. For such a condition, the lens muscle will relax and permit the lens to become thinner. When the lens has taken the thinner shape, it bends the rays of light just enough to focus a sharp dot on your retina. But if you should be looking at a nearby dot of light, a thin lens would not bend the rays of light enough and that would make the dot out of focus. To prevent this, the lens muscle contracts, so the lens becomes thicker. The thicker lens then bends the rays more and the dot comes into focus on the retina of your eye.



THE LENS FORMS AN IMAGE ON THE RETINA

After the image has been thrown into focus on the retina, certain of the rods and cones will be lighted up, while others will be dark. When you look at the dot of light, relatively few of the rods and cones are brightly lighted, while those around them are in the dark. The lighted rods and cones are stimulated to send messages, or nerve impulses, to the brain. Those that are lighted report the fact to the brain, and the brain interprets the reports from the lighted rods and cones as a small circle of light.

You might think that a strong light on a rod or cone would cause it to send a strong nerve impulse, while a weak light would produce a weak impulse. However, every nerve impulse has the same strength! But with a weak light, the rod or cone sends nerve impulses relatively infrequently. The stronger the light, the more often the rod or cone produces nerve impulses.

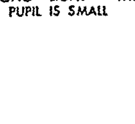
These nerve impulses, or signals, enter the visual center of the brain through connecting nerves. The visual center is a group of special brain cells that interpret the signals from the rods and cones, and put them together into a "picture." When a rod or cone is sending in messages only infrequently, the brain cells connected to that rod

or cone are receiving only a few messages. When a rod or cone sends in messages frequently, the connected brain cells are receiving many messages.



Now let's compare these brain cells with dots on a printed page. Look at a picture in a newspaper. If you look closely, you can see that it is made up of dots of different sizes. Where there are many large dots, the area is dark. Where the dots are small, the area is light. When you hold the picture away from you, the dots blend into each other so that you see only a picture made up of varying gray tones. In a similar way, the brain cells in the visual center are variously stimulated to "form" large or small "dots." The visual center puts these dots together into the image that we see with our eyes.

Persistence of Vision



IRIS CONTRACTED IN STRONG LIGHT — THE PUPIL IS SMALL

When you look at a light and then look away, you will continue to "see" light for a moment. This is because the rods and cones do not instantly stop sending their messages to the brain after the light stops shining on them. They continue to report "light," even though the light is gone. Normally, this goes on for only a fraction of a second. This action is called *persistence of vision*, because your eyes persist in "seeing" the light after it is gone. This is very important to us when we are looking at a motion-picture or television screen; but we'll hear more about that in a later chapter.

If the light is very strong, the rods and cones will continue to send their messages for several seconds after you look away from the light or close your eyes. You have probably been temporarily "blinded" by looking into a strong light. This is not pleasant and can be rather painful.



THE IRIS EXPANDED IN WEAK LIGHT—THE PUPIL IS LARGE

The eye tries to protect itself against too much light; and it has a special muscle, called the "iris," to do that job. The iris is a circular muscle in the front part of the eyeball, with a hole in its center. This hole is the pupil. The iris is the part of the eye that you refer to when you say someone has blue or brown or black eyes. When the light is strong, the iris contracts, to make the pupil small; and when the light is weak, it expands to make the pupil large. When the pupil is large, much more light can get in. You can test the iris action in your own eyes by looking into a mirror in a dim light and then turning on a bright light. You will see the pupil suddenly become small.

Color

When a piece of iron is gradually heated, it begins to glow a dull red. Soon it turns bright red, then orange, yellow, bluish-white; finally, when it is "white-hot," it gives off a strong white light.

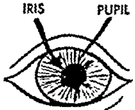
The explanation for this is that many of the orbit-hopping electrons jump shorter and shorter distances as the iron becomes hotter and hotter. These shorter and shorter "hops" result in shorter

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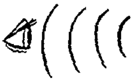
we have already mentioned, light results when electrons move very short distances, or from one atomic orbit to another. When the distance over which the electrons move is somewhat greater, the electromagnetic waves produced are longer; these longer waves produce the sensation of heat.

We have found out that radio waves, heat waves, and light waves are all electromagnetic waves of different lengths. We have to use a radio to receive the radio waves. Our eyes respond to the light waves. And certain nerve endings in our skin respond to the heat waves so we "feel" heat.

The heat waves, however, produce another action. They warm nearby objects. That is, they speed up the molecular activity and make the molecules of these nearby objects move faster. They produce this action in somewhat the same way that radio waves make electrons move back and forth in a receiver antenna. As they strike an object, they set the molecules of which the object is made into faster motion, so that the object becomes "hot."



RADIOS RECEIVE RADIO WAVES



EYES RECEIVE LIGHT WAVES



CERTAIN NERVES RECEIVE HEAT WAVES



ONLY RED WAVE LENGTHS ARE REFLECTED



and shorter electromagnetic waves. Some of the cones in the eye respond to the longer electromagnetic waves, others to the shorter. On that account, some of the cones "see" the red, others "see" the blue. They not only report to the brain how much or how little light they are receiving, but they also report what colors the light is.

When all the visible colors are being reported together, the brain interprets this as "white" light. White, then, is a combination of the various colors that cones can "see."

When white light shines on a white object, almost all of the light is reflected, so the object is white. But if the object is red, the coloring matter absorbs all the wavelengths except red. Only the red is reflected to our eyes, so the object looks red to us.

The coloring matter, or dye, on any object that we see by reflected light acts much like a sieve. It allows certain wavelengths to sift through, but bounces back others. A black object allows almost all wavelengths of light to sift through. Little or no light is bounced back, or reflected, and we therefore say that the object has no color, or is "black."

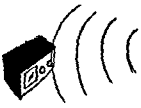
Heat

An object heated to a high temperature not only gives off light; it also gives off heat. When you stand in front of a fire, you can *see* the light and *feel* the heat from it. These two different sensations are both produced by electrons in motion. As

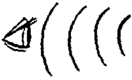
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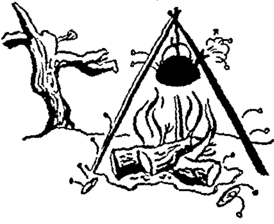
RADIOS RECEIVE RADIO WAVES



EYES RECEIVE LIGHT WAVES



CERTAIN NERVES RECEIVE HEAT WAVES



ONLY RED WAVE LENGTHS ARE REFLECTED



and shorter electromagnetic waves. Some of the cones in the eye respond to the longer electromagnetic waves, others to the shorter. On that account, some of the cones "see" the red, others "see" the blue. They not only report to the brain how much or how little light they are receiving, but they also report what colors the light is.

When all the visible colors are being reported together, the brain interprets this as "white" light. White, then, is a combination of the various colors that cones can "see."

When white light shines on a white object, almost all of the light is reflected, so the object is white. But if the object is red, the coloring matter absorbs all the wavelengths except red. Only the red is reflected to our eyes, so the object looks red to us.

The coloring matter, or dye, on any object that we see by reflected light acts much like a sieve. It allows certain wavelengths to sift through, but bounces back others. A black object allows almost all wavelengths of light to sift through. Little or no light is bounced back, or reflected, and we therefore say that the object has no color, or is "black."

HEAT

An object heated to a high temperature not only gives off light; it also gives off heat. When you stand in front of a fire, you can *see* the light and *feel* the heat from it. These two different sensations are both produced by electrons in motion. As

It was not until 1822 that the chemical processes of photography were improved enough to permit the taking of successful photographs. Even then, the earliest photograph was a very poor one, and many hours were needed to make it. Nevertheless, the man who made the first photograph, J. N. Niepce (nyĕps), a Frenchman, was elated at this degree of success after his many years of experimenting and work. It was a beginning of something important.



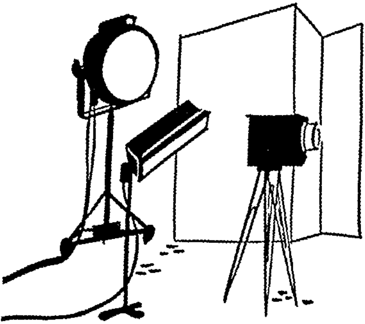
DAGUERRE

A few years later, another Frenchman, Louis J. M. Daguerre (dȧ'gâr'), made several improvements in the chemical processes used in photography. In 1829, Niepce and Daguerre formed a partnership. By 1839, after 10 years of difficult labor, they had worked out the first reasonably good photographic method. In place of the film and paper that are now used, they made photographs on metal sheets. These photographs were called "daguerreotypes" (dȧ-gâr'ō-tīps) (after Daguerre) or "tintypes."



A TINTYPE

This photographic process was still rather cumbersome and slow, and other men were seeking still better ways of taking photographs. Talbot, in England, invented a means of making photographs on chemically treated paper as early as 1839. Although this process was improved during the next few years, it was still not entirely satisfactory. Then, in 1889, George Eastman, in the United States, produced a flexible and transparent photographic film, very much like the film used today. This film, after exposure in a camera, can be developed by certain chemical processes. Finally,



Chapter Twenty-three

PHOTOGRAPHY

ALEXANDER Graham Bell had the idea of making a mechanical ear that would react to sound; this idea led to the invention of the telephone. Thomas Alva Edison wanted to make a permanent record of sound or music; his talking machine was the result. In a somewhat similar manner, men of past centuries studied the human eye and perhaps wondered whether a mechanical "eye" might be built that would produce a permanent record, or picture, of a scene.



THE FIRST CAMERAS MERELY THREW AN IMAGE ONTO A FLAT SURFACE. THEY TOOK NO PICTURES.

The basic principles of the mechanical "eye" that we know as the *camera* were described as long ago as the twelfth century A.D. by Alhazen, an Arabian. Baptista Porta (bät-tēs'tă por'tă), in 1553, is supposed to have invented the first camera. But it was a crude affair, which did no more than throw a small image of a scene onto a flat surface. Of course, at that time, there was no such thing as photographic film that could be used to make a permanent record of the scene.

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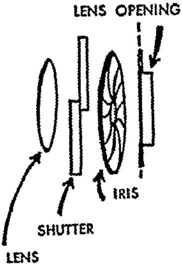


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prints, or copies, of the picture can be made from the film on photographic paper. Before we think more about the details of these processes, let us see how the camera itself works.

The Camera



To an amazing degree, the photographic camera is constructed like the human eye and functions like it. The eye has an iris, a lens, a retina, and an eyelid, which can be shut to close off the light. The camera also has an iris, a lens, a "retina," and an "eyelid."

In the camera, the iris has the same function as the iris in the eye. Both vary the size of the opening through which light enters. When there is considerable light, the iris in the eye contracts to make the pupil smaller, so that less light is admitted to the eye. Likewise, the camera iris can be "stopped down," as photographers say, to admit less light.

CAMERA—IRIS OPEN



The camera's "eyelid" consists of a shutter that can be opened and closed. When it is open, light enters the camera. The shutter must normally be opened only a fraction of a second, when a picture is being taken. If it stays open too long, too much light shines on the camera's "retina." If this should happen, the picture would be ruined by "over-exposure." We'll hear more of that later.

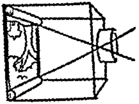
CAMERA—IRIS STOPPED DOWN



The camera lens is made of glass and can be adjusted by being moved nearer to or farther from the back of the camera, where the "retina" is located.

This adjustment is called "focusing." In a properly focused camera, the lens throws a sharp, clear image of the scene that is being photographed onto the camera's "retina."

The "retina" in the camera is the photographic film, and it, like the retina in the eye, is sensitive to light. The film is made of a transparent plastic material that is coated with gelatin. The gelatin contains a great number of tiny particles of silver bromide (brō-mīd), a chemical compound made up of silver and bromine. There are millions of these tiny particles on every square inch of the film. When light falls on one of these particles, some of the molecules of silver bromide split up into bromine and silver atoms. If the light is weak, only a few molecules split up; but if the light is strong, many molecules split up.

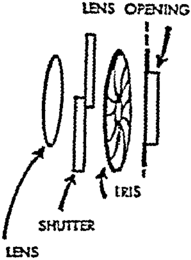


THE RETINA IS THE FILM

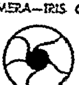
After the film has been exposed to the light in the camera, it is removed from the camera and put into a developing solution. This chemical fixes the atoms of silver on the film. Then the film is washed in a "hypo" bath, which removes any unsplit silver bromide molecules. That leaves only the silver atoms. Finally, the film is washed in clean water and then dried.

The film is now very black where strong light hit it in the camera and transparent where little light hit it. Under a supermicroscope, the black areas would show up as large numbers of silver atoms. Because the light parts of the scene that was photographed appear very dark on the film, and the

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CAMERA—IRIS STOPPED DOWN



The Camera

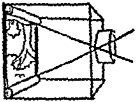
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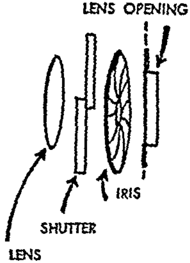
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so that the proper amount of light will enter the camera. Finally, he adjusts the shutter speed so that the shutter will remain open the proper amount of time. This exposes the film to the light for the correct length of time and is of great importance. If the exposure is too long, the film will be "overexposed"—that is, so much light will get in that most of the silver bromide molecules on the film will split. This leaves so many silver atoms on the film that it is very black all over and prints would be much too light to be satisfactory. If the shutter is open too short a time, the film will be underexposed; not enough atoms of silver will be left on the film and the film will be practically transparent all over, resulting in excessively dark prints.

After the photographer snaps your picture, he processes the film and makes prints from it. These prints, or photographs, are then a permanent record of the way you looked when you had your picture taken. In the year 2000, your grandchildren can show these pictures to their friends and say, "That's how granddad (or grandma) looked when he (or she) was young!"

PRINT MADE FROM UNDEREXPOSED NEGATIVE



PRINT MADE FROM OVEREXPOSED NEGATIVE



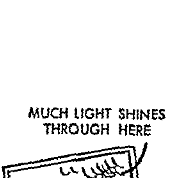
JUST RIGHT



Color Photography

You probably have seen natural-color photographs and have marveled at the beauty that photographic film can capture. Marvelous, too, is the way that color film does this. Color film is very much like the black-and-white film we have been

darker parts appear light, the film is called a "negative." Everything on it is the reverse, or negative, of the original scene.





AND THE FINISHED PRINT LOOKS LIKE THIS

Prints are made from the negative by use of photographic paper. This paper is coated with much the same chemical material as the photographic film. The negative film is laid on top of the paper, and a strong light is allowed to shine through the film. Where the negative is dark, very little light shines through. Where the negative is transparent, much light shines through. These variations of light cause varying amounts of silver atoms to break loose from the silver bromide molecules on the paper. Then, when the paper has been treated in chemical baths, dark and light areas appear in the right places to produce a picture of the original scene that was photographed.

Having Your Picture Taken

If you were to have your picture taken at a photographer's, he would ask you to sit in front of his camera. Then, he would turn on some lights, look through the camera at you, and adjust the camera. Finally, he would close the camera shutter, load the camera with film, ask you to sit still for a moment and smile, and then he would "snap" your picture.

As he adjusts the camera, he does three things. He moves the lens back and forth to bring your image into sharp focus. Then he adjusts the iris

so that the proper amount of light will enter the camera. Finally, he adjusts the shutter speed so that the shutter will remain open the proper amount of time. This exposes the film to the light for the correct length of time and is of great importance. If the exposure is too long, the film will be "overexposed"—that is, so much light will get in that most of the silver bromide molecules on the film will split. This leaves so many silver atoms on the film that it is very black all over and prints would be much too light to be satisfactory. If the shutter is open too short a time, the film will be underexposed; not enough atoms of silver will be left on the film and the film will be practically transparent all over, resulting in excessively dark prints.

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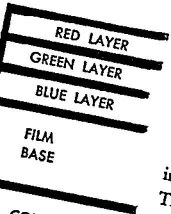
JUST RIGHT



Color Photography

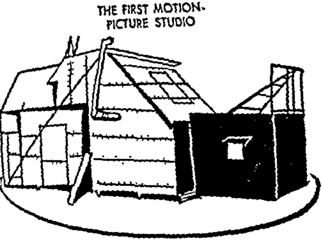
You probably have seen natural-color photographs and have marveled at the beauty that photographic film can capture. Marvelous, too, is the way that color film does this. Color film is very much like the black-and-white film we have been

discussing. However, it has three layers of gelatin instead of only one. Each layer contains a great number of silver bromide particles. The first layer is sensitive to blue light, the second layer to green light, and the third to red light. When the film is exposed in a camera, and then developed, the three layers turn into three images, one on top of another. One layer is blue, the second green, and the third red.



COLOR FILM
ATLY MAGNIFIED—
CROSS-SECTION

When light shines through the negative, the three images blend to form the color picture that you see. The color negative can be used to make prints, just as with the black-and-white negative. To make color prints, a special photographic paper is required. This paper has three layers of gelatin, much like the color negative. When the negative is used to make a print, it is placed over the paper under a strong light. Then the print paper is treated in chemical baths, and the three layers on the print paper take on the colors of the negative.

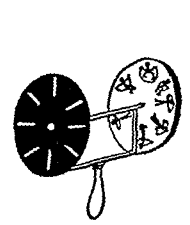


Chapter Twenty-four

MOTION PICTURES

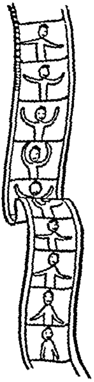
When you go to a motion-picture show, you may not give much thought to what makes the pictures "move," and to the men who worked out the process by which they are made to move. Thomas Alva Edison is given the credit for having invented motion pictures, but he would have been the first to admit that many other men who came before him must share the credit. Long before Edison's time, as we noted in Chapters Twenty-one to Twenty-three, men were studying light, the human eye, and the camera. In addition, other men were studying electricity and learning how to produce it and use it.

One of the early students of the human eye whose work was of particular importance to the development of motion pictures was Peter Mark Roget (rō-zhā'), an Englishman. In 1824 he reported some interesting facts about the persistence of vision. A few years later, Dr. Joseph Antoine



Platum, in Belgium, and Dr. Simon van Stompfer, in Vienna, made use of the persistence of vision in certain devices they built. These devices consisted of disks with series of small drawings on them. When the disks were rotated, the drawings seemed to blend so as to produce a moving picture. Then in 1860, Coleman Sellers, in the United States, made a similar device. Instead of drawings, however, he used a series of pictures of his son driving a nail.

These devices could show but a few moments of action, because one of the rotating disks could not hold very many pictures. Edison realized that, in order to show a long sequence of actions, a long strip of pictures was necessary. When Eastman perfected his photographic film in 1889, he furnished Edison with a material that could be made in long strips to contain a great many pictures. Edison made use of this film in his motion-picture camera, and he put a strong light behind it to flash a series of still pictures onto a screen. The pictures blended; there was motion, action. A new industry—motion pictures—was born.



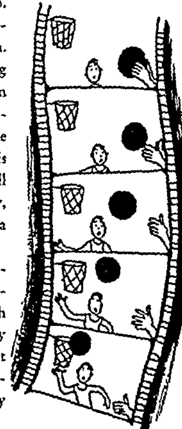
How the Pictures Move

But how can a series of motionless, or still, pictures be blended on a screen to produce motion pictures? To understand this, we must first remember that our eyes have a peculiar habit, called "persistence of vision," that causes them to continue to "see" a light for a moment after that light is turned off.

You can test this for yourself by looking steadily for a few seconds directly at the dot in the center of the star on this page. Then look away at the wall and blink your eyes rapidly. You will continue to "see" the star for some moments.



In somewhat the same way, when a still picture is flashed on a screen and is then suddenly turned off, the eyes will continue to "see" it for a fraction of a second. If, in the meantime, a second still picture is flashed on the screen, the eyes will not be conscious that the screen has been momentarily darkened. Suppose that the first picture shows a basketball soaring through the air toward the hoop. It has just left the player's hands. The second picture shows it an inch or so farther along in its path. Then a third picture is flashed on the screen showing it still farther along. Other pictures follow in rapid succession, each one showing the ball advanced in its path a little farther than in the one before. To the eyes, as persistence of vision fills in the dark intervals between pictures, the ball seems to move swiftly toward the hoop and, finally, to swish the net for two points, if the shot was a good one.



The pictures follow one another in swift succession; every second, twenty-four separate pictures flash on the screen, one after another. Each picture is on the screen for so short a time, and they follow one another so rapidly, that the eyes cannot distinguish individual pictures. They all blend together in the eyes to produce the effect of actually "moving" pictures.

Making a Movie

The script calls for the hero to raise his hand to his head. The lights are turned on, the camera is focused on the hero. At a signal from the director, the camera is set into operation and the hero begins to raise his hand to his head.

This is what happens in the camera. The strip of film moves along nearly an inch, stops, and the camera shutter swiftly opens and closes. A still picture, about $\frac{5}{8}$ by $\frac{7}{8}$ inch in size, has been taken. The film is given a quick pull so that it moves along another inch; the shutter opens and closes again to take another picture. This occurs twenty-four times every second. Each time, the shutter opens and closes so rapidly that the action is "stopped" —in other words, the picture that is taken shows no movement; it is a still picture.



THIS IS THE ACTUAL SIZE OF EACH OF THE PICTURES THAT MAKES UP A MOVIE

Each successive picture shows the hero's hand in a slightly higher position. The first shows it at his side. The second shows it raised a fraction of an inch, the third shows it still higher. In all, it might take fifty pictures to show the entire action of the hand moving up to the head. When the strip of film is developed and run through a movie projector, persistence of vision in the eye blends the sequence of still pictures into a moving picture.



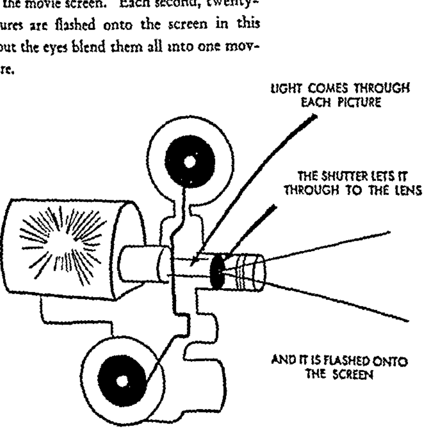
SOME WIDE-SCREEN MOVIES USE PICTURES THIS SIZE

Actually, the original film is not run through the projector. Prints of the film are made on other strips of film by a process much like that used to make photographic prints from negatives. These

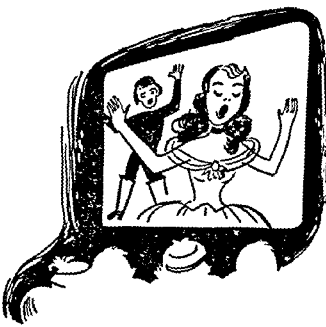
prints are then sent out to the movie theaters. Hundreds of prints can be made from a single original film, so that the same movie can be shown in many places at the same time.

THE PROJECTOR

When the film is run through a projector, each still picture is positioned before a strong light and a shutter is quickly opened and closed. The light thus shines through the picture and throws an image of it onto the movie screen. Each second, twenty-four pictures are flashed onto the screen in this manner, but the eyes blend them all into one moving picture.



Chapter Twenty-five
THE MOVIES TALK



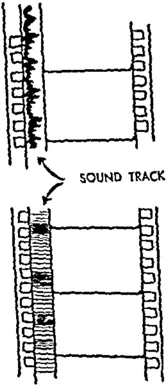
THOMAS Alva Edison was a remarkable man. He proposed not only that pictures should "move" on a screen, but also that they should "talk." No later than 1890, he combined his moving-picture projector with his talking machine, to produce talking motion pictures. But the sounds that came out of the talking machine, or phonograph, were weak. The amplifying electron tube had not yet been invented. Therefore, even though the moving picture could be made large enough for many people to see it, the sound was so weak that only a few people could hear it. The further development of talking pictures had to wait for many years, until electron tubes were perfected.

Finally, however, men found a way of making a photographic record of sound. This record is played in the motion-picture theater as the picture is shown, and the resulting sound is amplified, so

that the audience not only sees the movie, but hears it as well.

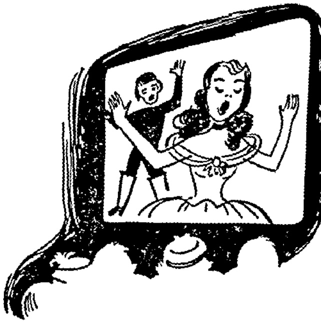
Photographing Sound

If you should look at the strip of film that is run through a motion-picture projector to produce talking pictures, you would see a series of still pictures. These produce the moving pictures on the screen. Also, you would see a narrow strip near one edge of the film that would contain either a wavy line or dark and light areas. This narrow strip is called the "sound track," and it is actually a continuous photograph of the speech, music, and other sounds that you hear in the motion-picture theater.



When a motion picture is made, the visible action is photographed and, at the same time, the words the actors speak are "photographed" on the same film. This sound photography is accomplished by changing the sound into light, and then shining the light through the film sound track.

The sound is changed into light by a series of special electron tubes. First, the sound is picked up by a microphone, which converts the sound into electric impulses. This is the same thing that happens in a telephone. These impulses are amplified in electron tubes and then carried through a special electric-light bulb. This is not the same sort of light bulb that you use in your home, but a tube that can vary greatly in brightness in an exceedingly

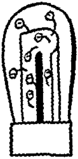


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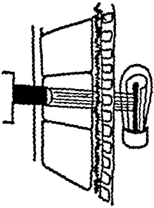
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Reproducing the Sound



The *phototube* (fō'tō-tūb'), a very special type of electron tube, is the heart of the talking-picture projector. It has the job of changing the photographs of the sound on the film sound track back into sound again. The phototube does not do the whole job, but it takes care of the first important step.

The phototube is a special electron tube containing two parts—a curved metal sheet and a metal rod. The metal sheet is coated with a certain special material, such as cesium (sē'zĭ-ŭm). This material engages in an odd activity when light shines upon it —it gives off electrons. The atoms of the material do not have a very firm hold on some of their electrons. When light strikes these atoms, electrons are knocked loose. This is called the "photoelectric effect." The electrons thus freed in the phototube cross over to the metal rod—in other words, electricity flows from the metal sheet to the rod.



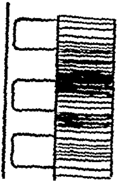
When the light is strong, many electrons flow to the rod, and when the light is weak, only a few flow; so a flow of electricity results that varies in strength with the varying brightness of the light.

In the talking-picture projector, the phototube is placed in front of the film sound track. A strong light is placed at the back of the sound track, so that light shines through the track into the phototube. When the track is dark, little light can shine

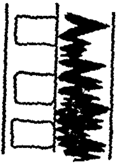
short time; it can change from bright to dim and back to bright in a few millionths of a second.

Thus, the sound is changed into electric impulses and then into light impulses. A strong sound will produce a strong light, and a weak sound will produce a dim light. When this light of varying strength is made to shine through the sound track of the film, it causes varying numbers of silver atoms to appear. This is the same action that takes place when a photograph is made. The silver atoms appear as the silver bromide molecules split up because of the action of the light.

VARIABLE-DENSITY TRACK



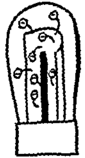
VARIABLE-AREA TRACK



After the film is developed, the sound track will be light or dark according to whether the original sound was weak or loud. One part will be dark, indicating a loud sound; another part will be light, indicating a weak sound. When the sound track passes through the motion-picture projector, the sound will be reproduced in the way explained below. Then, as you sit in the audience, you will hear the orchestra play and the actors speak.

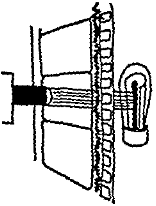
The type of sound track that has just been described is called a *variable-density* track, because it varies from transparent to very dark, or dense. There is a second sort of sound track that consists of a wavy line. This is called a *variable-area* track, because the dark area covered by the wavy line varies. Both sound tracks have the same effect when they are used in the motion-picture projector.

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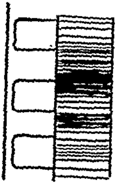
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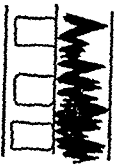
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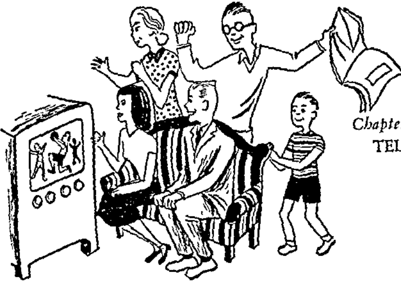


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Chapter Twenty-six
TELEVISION

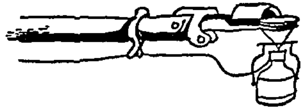
WITH motion pictures, a scene in a studio can be captured on film and reproduced at any later time on a screen in a theater. But with television, the scene in the studio is reproduced, without a second's delay, on the viewing screen in the television receiver. There is no in-between period of developing and copying the film and shipping it to the theater. In television, the scene is translated into electric impulses, which in turn are broadcast as electromagnetic, or radio, waves. The receiver then converts the electromagnetic waves into electric impulses, which finally are changed into light. This light appears as a pattern of moving dots of light on the receiver screen to reproduce the scene in the studio. Astonishing as it seems, this whole series of actions takes place in a tiny fraction of a second.

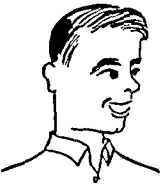
The names of the men who have made television possible would make a long list indeed. The list

through; but when the track is transparent, a strong light shines through into the phototube.

In this way, the light and dark areas of the sound track result in light impulses of varying brightness; and these varying light impulses are changed in the phototube into electric impulses of varying strength. The electric impulses are then amplified in electron tubes, which are similar to the amplifying tubes used in radios. The greatly strengthened electric impulses finally pass through a loudspeaker, which changes them into sound.

This is certainly a fascinating process. When an actor says, "Good morning" in the studio, the sound is changed into light impulses so that it is, in effect, photographed on the film. In the motion-picture theater, the photograph is changed back into sound with the help of the phototube, so that you hear the actor say, "Good morning."





electric impulse. If the dot is small, the impulse is small; if the dot is large, the impulse is large.

After the dot changer has scanned the first line of dots, it jumps to the left and starts across on the second line. This is the same way that your eyes move when you read a book. You read from left to right, moving down from line to line toward the bottom of the page.

As the dot changer thus changes one dot after another into an electric impulse, the receiver changes these electric impulses of varying strength into "dots" of varying sizes. The action is so fast that the dots blend to produce a moving scene of the action that is going on in the television studio.

The Camera Tube

The "dot changer" we have been referring to is a very special sort of electron tube which is the heart of the television camera. There are different kinds of camera tubes, but all work on the same general principles. One type is the *iconoscope* (ī-kŏn'ō-skōp). It contains three essential parts—a *mosaic*, a *collector ring*, and an *electron gun*.

ICONOSCOPE



The mosaic consists of a metal plate covered with insulating material. One surface of the insulating material contains hundreds of thousands of tiny globules, or round spots, of silver, each coated with a special substance such as cesium (the same material used in the phototubes described in the previous chapter). So each spot of silver acts like a tiny

would include all those earlier scientists who studied and experimented with light, electricity, and radio. Besides, it would certainly include the names of those latter-day scientists such as Boris Rosing and Dr. Vladimir Zworykin who built upon the knowledge that the earlier scientists had accumulated, to create the marvel of television.

How the Picture Is Telecast

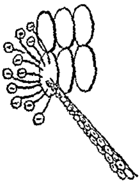
Before a picture can be broadcast, or *telecast*, it must be broken down into a series of tiny fragments. To get some idea of how a picture can be broken down in this manner, look closely at a newspaper picture, as you did when we were talking about the way the rods and cones in the eye work to produce a picture. Note that this newspaper picture is made up of row after row of tiny dots. Some of the dots are large, some small. Many large dots together produce a dark area; small dots together produce a light area.

THE DOT CHANGER WOULD MOVE ACROSS THE SCREEN LIKE THIS, BUT THE LINES WOULD BE MUCH CLOSER TOGETHER, IN ORDER TO COVER EVERY DOT

If every one of these dots were changed into an electric impulse (strong impulses for large dots and weak impulses for small dots), the first step in telecasting the picture would be made. Suppose that, for the moment, we call the instrument that changes dots into electric impulses a "dot changer." To telecast the picture, the dot changer starts in the upper left-hand corner of the picture and moves across the top line of dots. As it comes to each dot in turn, the dot changer changes the dot into an

plate. However, some of them stream through the hole, just as light would stream through a hole in a piece of cardboard held in front of a lighted lamp bulb. This electron stream, fine as a hair, is then bent one way and then another by two sets of plates placed at right angles to each other.

IF A "PHOTOTUBE" HAS LOST 1,000 ELECTRONS, IT MUST GET THEM BACK FROM THE BEAM



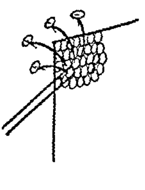
The first set of plates makes the electron stream bend up and down. This bending action is produced by putting different amounts of positive and negative charge on the plates. For instance, if a positive charge is put on the upper plate and a negative charge is put on the lower plate, the electron stream (composed of negatively charged electrons) will bend toward the upper plate and away from the lower plate. If the amount of positive and negative charges is varied, the electron stream can be made to bend up or down in varying amounts.

The second set of plates makes the electron stream bend to the right or the left. You see, then, that when the electric charges on both sets of plates are varied, the electron stream can be directed to any part of the mosaic.

In this way, the electron stream is made to start in the upper left-hand corner of the mosaic. It sweeps from left to right across the first row of phototubes, moves back to the left and sweeps across the second row, and so moves on down the entire mosaic.

The purpose of this is to restore to each phototube in turn the electrons that it lost when light

phototube. The mosaic is made up of hundreds of thousands of these tiny "phototubes."



When light falls on one of the phototubes, electrons leave it. The stronger the light, the more electrons are lost. Since the electrons are negative in electric charge, loss of electrons leaves the phototube positively charged. Therefore, any picture projected on the mosaic will be changed into a pattern of positive electric charges; or, we might say, the picture has been broken up into different-sized "dots" of electric charge.

The electrons lost by the phototubes are collected by the collector ring, and so are removed from the iconoscope.

The electron gun contains a filament and a plate with a small hole in it. The filament serves as the source of electrons. They fly out in all directions from it, but most of them are captured by the

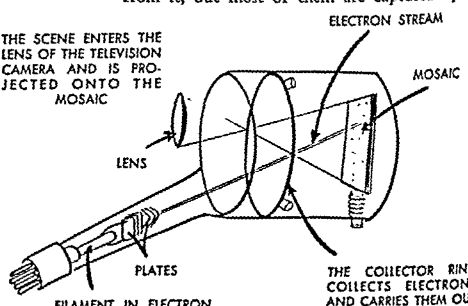
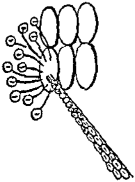


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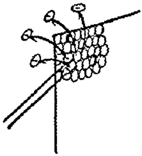
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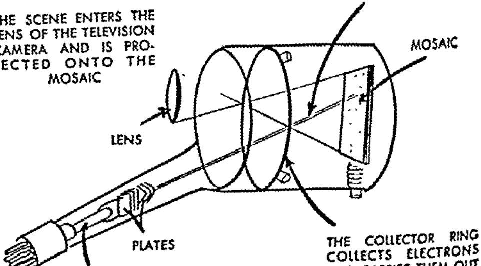
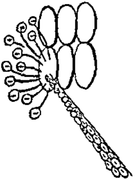


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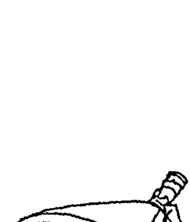
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These electrons, flowing from the metal plate, make up an electric impulse—an electric impulse that is proportional to the amount of light on the phototube. When the light is strong, the electric impulse is strong.

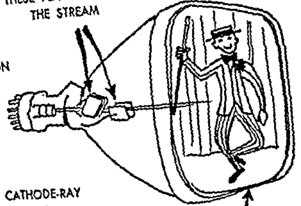


CATHODE-RAY TUBE

The impulses follow one another in rapid succession as the electron stream moves from phototube to phototube. They are then amplified and made to modulate the television carrier waves, much as the electric impulses from a radio microphone modulate radio carrier waves. The resulting waves produce electron motion, or electric impulses, in the television receiver. These impulses are then translated into a picture on the receiver screen.

The Receiver

The television receiver contains a very special sort of electron tube, called a "cathode-ray" (kăth'-ōd-rā') tube. This tube has an electron gun similar to the electron gun in the iconoscope. It shoots a stream of electrons onto a *fluorescent* (flōō-ō-rĕs'-ĕnt) screen in the tube end. This screen is coated



HOW THE CATHODE-RAY TUBE WORKS

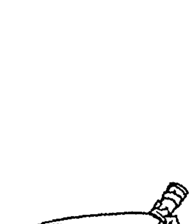
with fluorescent material that *fluoresces*, or glows with light, when electrons strike it. These electrons cause electron orbit hopping in the atoms of fluorescent material and, as we learned in Chapter Twenty-one, electrons that orbit-hop produce light. Thus, wherever the electron stream strikes the fluorescent screen, a dot of light appears. The stronger the electron stream, the brighter is the dot of light.

The electron gun in the cathode-ray tube bends the electron stream in exact step with the electron gun in the transmitter iconoscope. Both streams move across the tops of their respective screens together, and then scan the second, third, and lower rows in order.

The electron stream in the cathode-ray tube varies in strength as the electric impulses leaving the iconoscope mosaic vary in strength. When a strong impulse leaves the mosaic, the cathode-ray-

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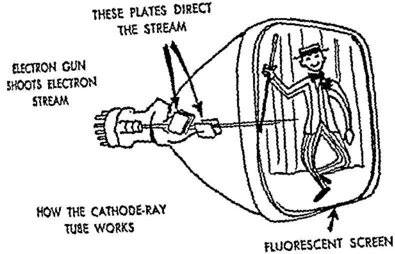


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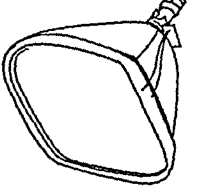
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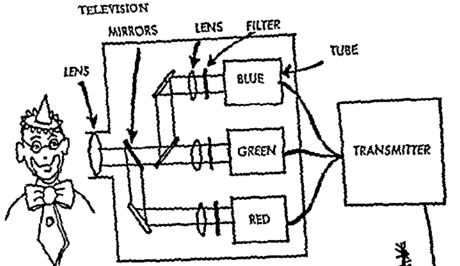


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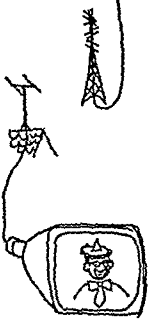
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s in the black-and-white picture tube. In addition, the fluorescent screen is coated with three different types of fluorescent materials. One type will glow blue, the second type *green*, the *third* type *red*. In operation, each of the three electron guns responds to only one of the three color pictures being telecast. For example, one of the electron guns works on the blue picture. In action, its electrons hit only the blue dots on the fluorescent screen. The second electron gun shoots electrons *only* on the green dots. Electrons from the third electron gun *hit only* the red dots. Thus the picture you see on the fluorescent screen of the picture tube is made up of three separate images. They blend to give you the color picture you see.



Television pictures sent out in color can also be received in black-and-white television sets. The black-and-white sets put the three different pictures together before they get to the electron gun in the picture tube. Thus the black-and-white picture tube shows the same picture, but it is in black and white only.

tube electron stream is strong; a bright dot appears on the fluorescent screen. If the impulse is weak, the dot is dim. Thus, the "dots" of varying electric charge on the iconoscope mosaic, produced by varying amounts of light from the scene that is being telecast, reappear on the fluorescent screen as moving dots of light. These bright and dim dots form a picture on the fluorescent screen of the scene that is being telecast.

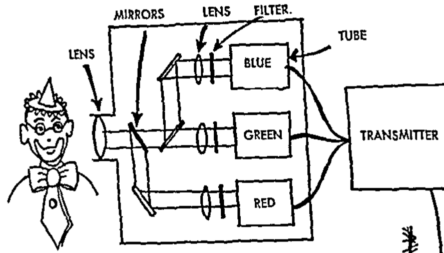
The entire screen is covered thirty times a second to produce thirty pictures every second. Our eyes, because of their persistence of vision, blend these separate pictures into a moving scene of the action that is taking place in the television studio.

Color Television

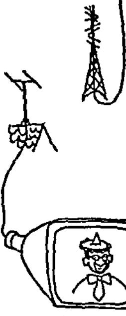
Do you remember how we take color photographs? We use a film that has three separate layers: one sensitive to blue, one sensitive to green, and the third sensitive to red. Blending these produces the different colors in the picture.

In the same way, color television breaks down the pictures into three colors—red, green, and blue. In effect, three separate pictures are telecast: one in red, one in green, and one in blue. A system of lenses, mirrors, and filters in the camera breaks the picture up in this way.

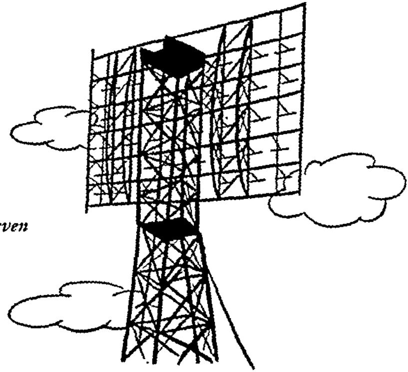
Then, in the receiver, the three separate pictures are put together again. One type of receiver color-picture tube has three electron guns instead of one,



as in the black-and-white picture tube. In addition, the fluorescent screen is coated with three different types of fluorescent materials. One type will glow blue, the second type green, the third type red. In operation, each of the three electron guns responds to only one of the three color pictures being telecast. For example, one of the electron guns works on the blue picture. In action, its electrons hit only the blue dots on the fluorescent screen. The second electron gun shoots electrons only on the green dots. Electrons from the third electron gun hit only the red dots. Thus the picture you see on the fluorescent screen of the picture tube is made up of three separate images. They blend to give you the color picture you see.



Television pictures sent out in color can also be received in black-and-white television sets. The black-and-white sets put the three different pictures together before they get to the electron gun in the picture tube. Thus the black-and-white picture tube shows the same picture, but it is in black and white only.



Chapter Twenty-seven

RADAR

TELEVISION makes it possible for us to see a distant scene as a transmitter at the television studio telecasts the scene to our receiver. But by means of *radar* (rā'dar), the outlines of distant objects are shown on the viewing screen on the receiver, even though there is no distant transmitter to telecast the scene. Perhaps even more remarkable than that is radar's ability to "see" in the dark or through heavy clouds. The pilot in an airplane equipped with radar, flying at night, can see on the radar viewing screen distant buildings, or perhaps a dangerous mountain peak that is miles ahead.

Radar can thus be used to guide airplanes through darkness to their destinations. During war, it enables bombers to find their targets at night or through heavy clouds. Ground radar sets can "see"

enemy planes at great distances through darkness or clouds, and can direct antiaircraft fire at them. Battleship radar sets permit accurate night bombardment of enemy ships or shore installations.

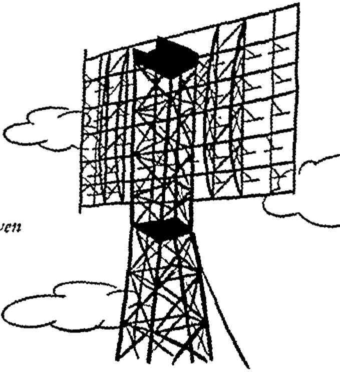
How Radar Works

Radar works on the "echo" principle. If you stood half a mile or so from a cliff, made a loud sound, and then accurately measured the time required for the sound to echo back, you could figure out to within a few feet how far away the cliff was. In a somewhat similar way, a radar set sends out radio waves, and then measures the amount of time it takes for the waves to return.

A radar set includes a transmitter and a receiver. The transmitter works somewhat like a radio broadcasting station, but the receiver operates more like a television receiver and translates the echoed radio waves into a sort of picture.

The transmitter is a very special sort of broadcasting station. It sends out, at regular intervals, short bursts of high-frequency radio waves. These waves are concentrated into a sharp beam. Each burst of waves lasts only about a millionth of a second, with pauses of a few thousandths of a second between bursts. In other words, the transmitter sends out waves for a millionth of a second, turns off briefly, and then comes on again, and it continues to do this for as long as the radar set is in operation.





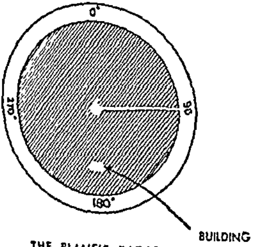
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will look like a crude map of the building in its relation to the airplane. The airplane position is indicated by the spot in the center of the screen. This will tell the pilot the exact location of the building in respect to the airplane. He can fly directly over it if he chooses, or he can turn away. You can see how valuable this instrument is to an airplane pilot at night, or to a ship's captain steering his vessel at night through iceberg-infested seas.

Ground radar can be used to detect airplanes in a similar way. The airplane shows up on the ground radar screen as a spot of light. Airports use radar to guide planes to a landing in foggy weather. The ground observer can see, by radar, where the plane is, and can "talk it down" by guiding the pilot in by radio.



THE PLANE'S RADAR SCREEN MIGHT LOOK LIKE THIS

These radio waves can go through clouds, and, of course, darkness does not hinder them. They continue to move out in a straight line from the transmitter until they strike something solid, such as a building. Then they reflect back, much as light is reflected when it strikes an object. The reflected waves, moving back to the radar set, are received and translated into a tiny spot of light on the cathode-ray-tube viewing screen.



Of course, if the sending beam were pointed in one direction only, it would not enable the receiver to supply much of an idea of the scene ahead. But in a radar set in an airplane, for example, the antenna of the transmitter keeps turning rapidly, so that it repeatedly *scans* the whole area below the plane. This is much like the scanning effect that takes place in the camera tube in the television transmitter.

Suppose that the area below the airplane is flat land. Each burst of radio waves will then shoot out and reflect back uniformly, and the whole surface of the cathode-ray-tube viewing screen in the receiver will be of uniform brightness. But suppose that the plane is above a tall building. The bursts of radio waves directed at the building, as the area is scanned, will have a shorter distance to travel to get back to the plane. These bursts that are reflected from the building, therefore, will be received ahead of those from the land around it, and will cause light spots to appear on the cathode-ray-tube viewing screen. The resulting "picture"

Later, other men were to prove that men's muscles were not strong enough to operate such wings and make flight possible; but for several centuries men experimented along these lines. They did not realize that a source of power, such as a gasoline engine, was necessary to make "flying machines" successful.



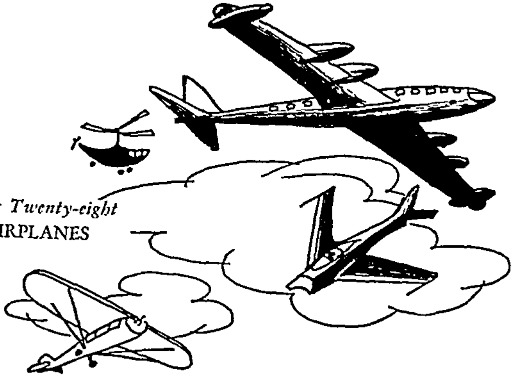
ONE OF DA VINCI'S WING-FLAPPING MACHINES

Leonardo da Vinci (lā-ō-nar'dō dah vēn'chē), the fifteenth-century Italian genius, who has great renown as a painter, sculptor, engineer, and inventor, worked out several wing-flapping schemes. But he went further. He suggested the use of a series of rotating wings to achieve flight, thus anticipating by 400 years our modern helicopter (hĕl'ĭ-kŏp'ter). He is believed to have been the first person who visualized the airplane propeller, and is even given credit for inventing the parachute!

By the beginning of the nineteenth century, many men were experimenting with flying machines of one sort or another, but their work was one long story of bitter disappointment. Although they had more or less settled on the principle of the fixed wing (as opposed to the flapping wing), they had no engines powerful enough for flight. Besides, they did not understand the principles of stability and control.

Gliding

Sir George Cayley, an English scientist, helped to establish the principle of the fixed wing with his small-model glider experiments shortly after



Chapter Twenty-eight
AIRPLANES

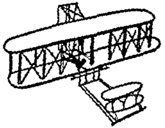
EVER SINCE men first began to study the flight of birds, they have probably wondered why they, too, could not put on wings and fly. The birds moved their wings and maneuvered with such apparent ease, it seemed reasonable to the ancient dreamers that men could do the same thing if they could devise some sort of movable wings. Ovid (ŏv'ĭd), a Roman poet who lived about the time of Christ, wrote a legendary story about two men who escaped from a prison by flying away on wings that they had made from feathers. Roger Bacon, an English scientist of the thirteenth century, was perhaps the first man to study the matter of flying in a scientific manner. He proposed a wing-flapping mechanism patterned after the wings of birds; he thought that movement of the arms and legs would operate the wings so that a man could fly.

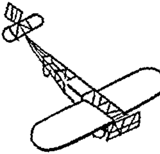
stalling or diving. On a later page, we shall explain how this paper glider can be used to show the principles of airplane control.

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THE WRIGHTS' FIRST SUCCESSFUL PLANE



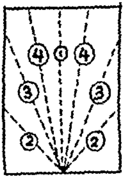


BLERIOT'S PLANE

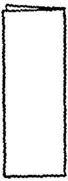
In the same year that saw Langley's failure, the Wright brothers, Wilbur and Orville, of Dayton, Ohio, succeeded. On December 17, 1903, at Kitty Hawk, North Carolina, their awkward, cumbersome craft, powered by a gasoline engine of their own making, lifted from the ground with Orville at the controls, and flew 120 feet. At that moment, their years of hard work were crowned with success, and the hopes and aspirations of others who had worked and planned, years before, were realized.

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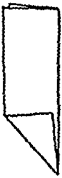
STEPS IN FOLDING THE PAPER GLIDER



THIS SHOWS FOLDS TO BE MADE



STEP 1



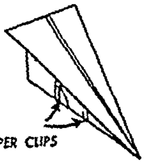
STEP 2



STEP 3



STEP 4



1800. In 1842, William Henson patented in England a sort of airplane that he called the "Ariel" (air'ĭ-ĕl). It was a crude construction, which he proposed to power with a steam engine (internal-combustion engines had not yet been invented). Henson even organized a company to provide regular flying service between European cities with his Ariels. But he was unable to build even one plane that would fly, so he finally gave up his work on them.

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Much still remained to be done, however. Larger and larger model gliders were being built, and, about 1855, a French sea captain named Le Bris is supposed to have built a glider large enough to carry him through the air for about an eighth of a mile. Other men, including the Lilienthal (lēl'yĕn-tahl) brothers in Germany, and Montgomery and Chanute in the United States, carried on the gliding experiments, and by the end of the nineteenth century gliding was almost commonplace.

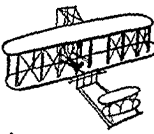
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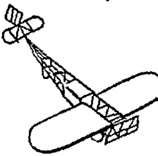
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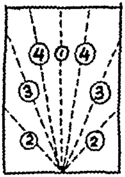


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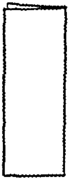
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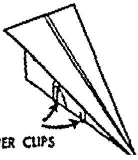
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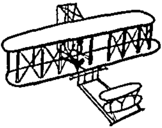
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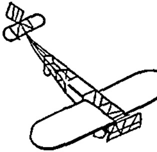
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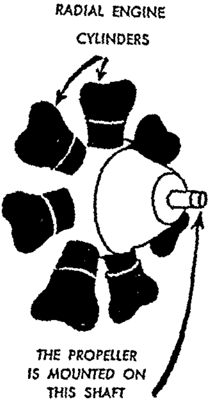
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an enormous plane for its time. It weighed about 3,000 pounds, and had four engines and a cabin with accommodations for sixteen passengers. This was a small plane, indeed, when compared with our huge modern planes weighing more than 200,-000 pounds and carrying more than a hundred passengers at speeds of several hundred miles an hour.



What Moves the Plane Forward?

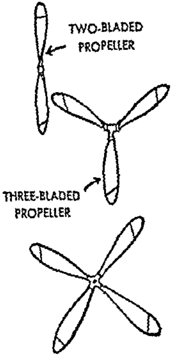
Before an airplane can begin to fly, it must be pulled forward through the air. The air through which the plane rushes then acts on the airplane's wings, causing the plane to lift, or to become airborne.

It is clear, then, that the first step in understanding how an airplane flies is to understand how the plane is pulled forward through the air. The propeller, which performs this job, is driven by an internal-combustion engine, much like the internal-combustion engines used in automobiles. There are differences, however. In the first place, airplane engines must be made as light as possible, because the lighter the engines, the greater is the load that the plane can carry. Also, many airplane engines have the cylinders arranged in a circle, instead of in a row. Such an engine is called a "radial" engine, because each cylinder is located on a radius of the circle in which the engine is enclosed.

The propeller is mounted on the engine shaft, so that it spins when the engine runs; and as the propeller spins, it acts on the air in such a way that it

is pulled rapidly through the air. Since the engine and the airplane are attached to the propeller, the whole plane is pulled through the air after it. Let us see just how the propeller does its part in making the plane fly.

The propeller may have two, three or four blades; and each blade may be considered a sort of scoop. As the propeller moves through the air, it "scoops up" air and pushes it backward. To look at this action from the molecular point of view, the molecules of air are momentarily pushed close together just behind the propeller blades. In other words, the scooping effect of the blades produces a high-pressure area behind them, so that the molecules bombard the backs of the blades harder than they do the front. The resulting pressure on the back of the blades pushes them forward, and so the propeller drags the plane through the air.



FOUR-BLADED PROPELLER

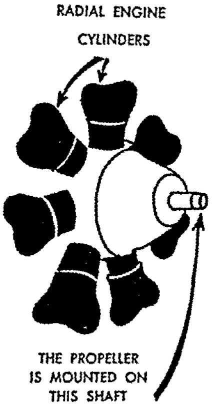
What Holds the Plane Up?

The plane is held in the air by a lifting effect on the wings as the wings are moved forward through the air. The wings are slightly curved on top, heavier at the front and trailing off to a thin tip. As the wing moves forward, it pushes the air out of the way. The air passing over the wing has to follow a curved path. Since this curved path is longer, the air molecules, in effect, have to "spread out" a little. This means that there are fewer air molecules directly above the wing than there are directly below the wing. The air pressure on any



AIR FLOWS OVER AND UNDER THE WING

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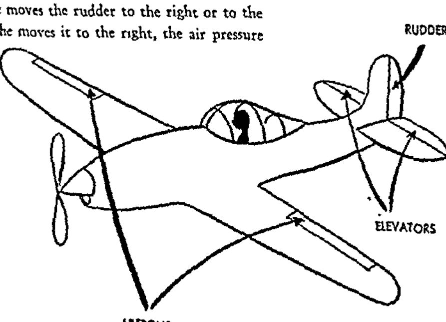
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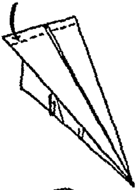
The ailerons are movable sections along the rear edges of the wings. Each wing has an aileron, and they are so connected by levers and cables that, when one moves down, the other moves up. The ailerons permit *banking*, or sideward tilting, of the plane. This is an important maneuver, particularly when turns are being made; for as one aileron is moved up, the air pressure on its top side forces that wing down. At the same time, the other aileron is moved down, so that its wing is forced upward. Thus the plane will circle to the right or the left, according to the direction in which the ailerons are moved.

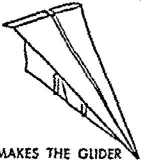
The rudder aids in turning. As the pilot operates pedals, he moves the rudder to the right or to the left. If he moves it to the right, the air pressure



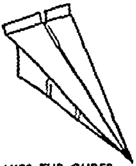
surface is determined by the number of air molecules at that surface. Since there are more molecules below the wing surface, the air pressure below *the wing is greater than that above the wing. In other words, there is an upward push on the wings when they are moved forward through the air, and this provides the lift that holds the plane in the air.*

BEND EDGES HERE





THIS MAKES THE GLIDER DIVE



THIS MAKES THE GLIDER GO UP

How Is the Plane Controlled?

The airplane must be guided, or steered, so that it will not only go left or right, but also up or down. This steering is accomplished by means of movable control surfaces in the wings and in the tail of the plane. These control surfaces are called the "ailerons" (ā'ler-ōns), "elevators," and "rudder."

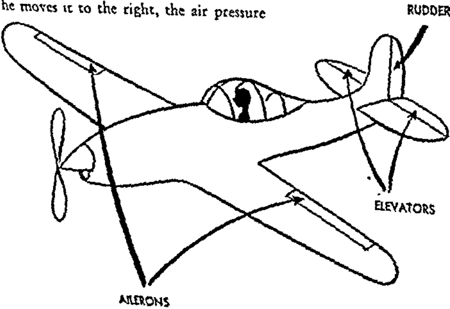
The tail of the plane has a fin and two stabilizers that keep the plane in balance when it is in flight. Attached to the stabilizers are two movable surfaces called "elevators." *The elevators are moved up or down as the pilot moves a stick or a wheel. When they are moved down, the air pressure under them becomes greater than that above them.* As a result, the tail of the plane is pushed upward. This means that the plane heads down, or "dives." On the other hand, *if the elevators are moved up, then the tail of the plane is pushed down and the plane climbs.*

You can *demonstrate these actions with your paper glider.* Bend down the back edges of the wings, as shown in the margin of the page, and see

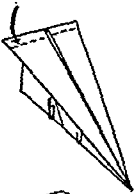
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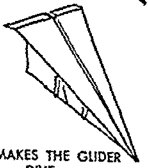


BEND EDGES HERE



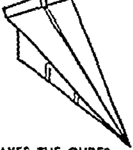
surface is determined by the number of air molecules at that surface. Since there are more molecules below the wing surface, the air pressure below the wing is greater than that above the wing. In other words, there is an upward push on the wings when they are moved forward through the air, and this provides the lift that holds the plane in the air.

How Is the Plane Controlled?



THIS MAKES THE GLIDER DIVE

The airplane must be guided, or steered, so that it will not only go left or right, but also up or down. This steering is accomplished by means of movable control surfaces in the wings and in the tail of the plane. These control surfaces are called the "ailerons" (ā'ler-ŏns), "elevators," and "rudder."



THIS MAKES THE GLIDER GO UP

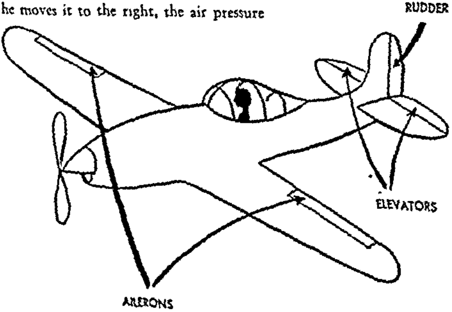
The tail of the plane has a fin and two stabilizers that keep the plane in balance when it is in flight. Attached to the stabilizers are two movable surfaces called "elevators." The elevators are moved up or down as the pilot moves a stick or a wheel. When they are moved down, the air pressure under them becomes greater than that above them. As a result, the tail of the plane is pushed upward. This means that the plane heads down, or "dives." On the other hand, if the elevators are moved up, then the tail of the plane is pushed down and the plane climbs.

You can demonstrate these actions with your paper glider. Bend down the back edges of the wings, as shown in the margin of the page, and see

how this makes the glider dive. Then bend the back edges up, and see how this makes the glider nose go up.

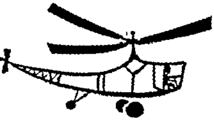
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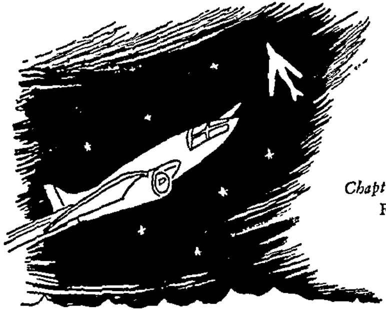
on it causes the tail of the plane to move to the left. This action, combined with the aileron movement, causes the plane to bank and turn. It is difficult to execute turns with rudder control alone. The forward movement of the plane will cause it to continue in the same direction, even though the rudder is used to force the tail to one side or the other. In other words, the plane will "skid" forward in its original direction of motion for some distance before a turn will take place; but if the plane is banked at the same time, by use of the ailerons, the whole plane will turn easily.

In a large airplane, the pilot would not be strong enough to move the control surfaces by himself. They are too large, and too much effort is required. Because of this, either electric motors or similar devices are used. The pilot operates controls that set the motors into action, and they then move the ailerons, elevators, and rudder.



The Helicopter

The helicopter, which was suggested by Leonardo da Vinci some four hundred years ago, is a rotating-wing device that spins a three- or four-bladed "propeller" above the plane to provide the necessary lift. Control is achieved by shifting the blades slightly, so that they provide more lift on one side than the other. For example, with a forward tilt, the helicopter will be pulled forward. If, however, the blades are not tilted, the helicopter can be made to hover motionless in the air.



Chapter Twenty-nine
REACTION ENGINES

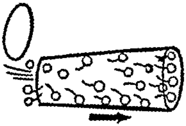
About two hundred seventy years ago Sir Isaac Newton, the famous English scientist, said, "For every *action*, there is an equal and opposite *reaction*." Yet no one could be more surprised than he would have been to see rockets and jet airplanes zooming across the sky at speeds of many miles a minute, in demonstration of this basic physical law. The jet engine used in such airplanes is a *reaction* engine; reaction pushes the plane through the air, just as reaction sends skyrockets into the heavens.



What Is Reaction?

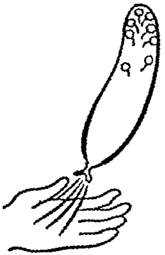
If we had a long cylinder that was shaped, for example, like a closed tin can and filled with highly compressed air, the molecules of air would bombard all sides and both ends of the cylinder. The cylinder would not have any tendency to move, be-

cause the same number of molecules would be bombarding each of its ends.



However, if we suddenly removed one end of the cylinder, the cylinder would tend to move. The movement would be in the direction of the closed end. The reason is that the molecules of air no longer have anything to bump against in the open end; but they would, for a moment, still bombard the closed end. This bombardment would tend to move the cylinder. In other words, the *action* of the molecules bombarding the cylinder end produces the *reaction* of cylinder movement.

Actually, the air would escape so quickly that the movement would be slight. But if it were possible to keep up a high pressure inside the cylinder, it would continue to be pushed along by the bombardment of molecules on the closed end. This is what takes place in the reaction engine. Fuel is burned to maintain the high pressure. A sustained push is the result.

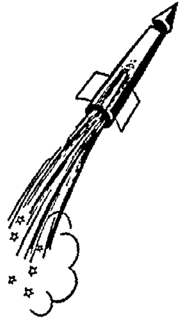


You can make a sort of reaction engine with an ordinary sausage-shaped rubber balloon. Blow up the balloon, lay it on the palm of your hand, and then let go of the mouth. It would be better not to do this experiment in the living room, or in any place where there are things that might get knocked over, for the balloon will take off and move around quite briskly for a moment or two, until the air gets out of it. Remember, the balloon moves, not because the air is rushing out the mouth, but because the molecules of compressed air in the balloon

are bombarding the closed front end of the balloon. They push the balloon forward.

Two Types of Reaction Engine

There are two types of reaction engine. They differ basically from each other as to whether or not they carry a supply of oxygen along with the other fuel. As you will recall, the burning of any fuel requires oxygen. The first type of reaction engine, known as the "chemical-fuel," or "rocket," reaction engine, carries along its own supply of oxygen. The second type of reaction engine, known as the "airstream" engine, depends upon the air to supply necessary oxygen.

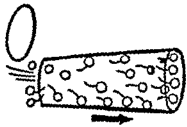


Chemical-fuel reaction engines

The skyrocket is probably the best-known example of the chemical-fuel reaction engine. It carries along its own oxygen, locked up in molecules of some chemical compound, such as gunpowder. Gunpowder is composed of sulfur, carbon, and potassium nitrate. This last has the chemical formula KNO_3 (one atom of potassium, one atom of nitrogen, and three atoms of oxygen to each molecule). When gunpowder is ignited, the oxygen and the carbon combine to form carbon dioxide (CO_2). Also, nitrogen is freed by the breakup of the potassium nitrate molecules.

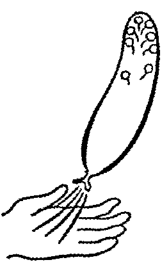
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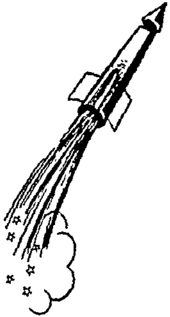


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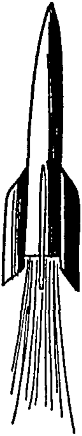
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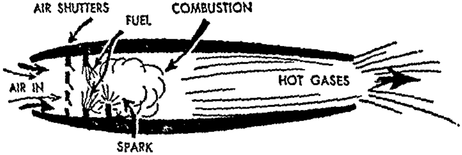
barding the confined space in the rocket cylinder. Since the back end of the cylinder is open, the molecules can fly out of that end freely. Therefore, the *action* of the molecules bombarding the closed front end of the cylinder produces the *reaction* that pushes, or *thrusts,* the rocket forward.

To make this clear, let us look at one swift-moving molecule that happens to be rushing forward toward the closed front end of the rocket cylinder. It strikes the front end and bounces off in the opposite direction. This molecule thus gives the cylinder a tiny forward push. If the rear end of the cylinder were closed, the molecule might then strike the rear end and give the cylinder a tiny backward push. These two pushes would more or less balance and the cylinder would have no tendency to move. But since the rear end is open, the molecule simply flies out of the rocket cylinder after it has given the cylinder a forward push. Think of billions upon billions of molecules doing this. Now you can see how these billions of molecules that rush forward, and bombard the front end of the cylinders, give the rocket a powerful forward push.

In the next chapter we will look more closely at rockets. Men have already sent rockets hundreds of miles into the air. One of these days, perhaps, a spaceship, powered by rocket engines, will take men to the moon, to Mars and other planets.

Airstream reaction engines

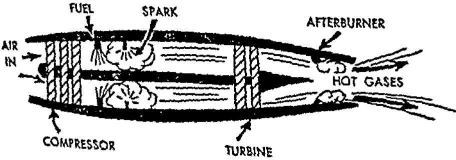
There are three types of airstream reaction engines: the *jet,* the *ram jet,* and the *turboprop jet.*



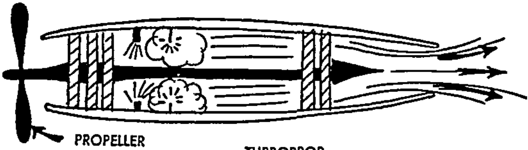
RAM JET

In all of these, the oxygen required for burning the fuel is taken from the surrounding air.

The ram jet is the simplest of the three. Essentially, it is a long tube with air shutters, a fuel-spraying system, and a spark plug at the front end. When the ram jet is moving forward at high speed, the movement "rams" air into the intake end. Fuel is then sprayed into the air and a spark sets it on fire. The combustion produces high pressure, which causes the air shutters to close momentarily. None of the high pressure can escape at the front end, and so the high-pressure gases must rush out the rear of the tube. Since the high pressure is contained at the front but released at the rear, it



TURBOJET



TURBOPROP

drives the ram jet forward. As soon as the high pressure is exhausted, the forward movement opens the air shutters so that more air can enter. Fuel is again sprayed into the air, and combustion once more takes place. These actions are repeated over and over again.

The jet and the turbojet are much more satisfactory for airplanes, because they supply an even thrust; the ram jet provides a series of hard thrusts, with coasts in between. The jet engine is also a long tube. It has a rotating mechanism which draws air into the combustion chamber. The rotating mechanism consists of a turbine at the rear, connected by a shaft to a compressor rotor. In operation, the turbine is spun by the high-pressure gases, and in turn spins the compressor rotor. The compressor rotor steadily draws air into the combustion chamber; fuel sprays continually into the compressed air, and it burns with a steady flame. Thus the combustion chamber is constantly filled with hot, high-pressure gas. This gas passes through the turbine and out the rear of the tube. The compressor contains the high pressure at the front, but the pressure is released at the rear. Therefore the

high pressure drives the jet forward. Many jets have an *afterburner*. This device, placed near the tail of the jet, sprays additional fuel into the stream of hot gas, providing additional forward thrust.

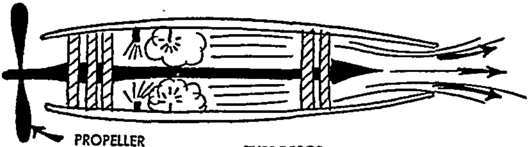
The turboprop engine is very much like the jet. It has an additional part, a propeller. Both the propeller and the exhaust jet drive the plane. The propeller is spun by the turbine. The turbine in the turboprop engine is larger and heavier so that it can handle this additional job. The turboprop engine will not move a plane as rapidly as a jet, but it is more efficient.

In these last two chapters we have discussed three types of engines for airplanes: the piston engine, the jet, and the turboprop. Since the latter two engines are newer, you may wonder if they will soon replace the piston engine. Scientists say this is not likely. The piston engine is efficient for relatively slow-speed, short-hop trips. For longer trips the turboprop is better, since it can move the plane at higher speeds and is a simpler engine in many ways. For the long trips from coast to coast, or across the oceans, the jet is favored. It can push the plane at speeds of as much as 600 miles an hour. This means you could fly from New York to California in about five hours!



The Sound Barrier

With improved piston engines, jets, and rockets, airplanes have been made to fly faster and faster.



TURBOPROP

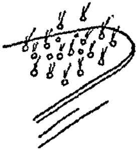
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see how breaking through this barrier can be very hard on the plane.

At speeds faster than the speed of sound, the plane leaves the sound waves behind where they cannot cause the plane any trouble. It is only when the plane passes through the sound barrier, either speeding up or slowing down, that the compression waves are encountered.

Men have worked out new plane shapes which enable the plane to go through this barrier with little difficulty. Such planes are called "supersonic" planes. *Sonic* stands for sound. Supersonic thus means faster than sound. The Douglas "Skyrocket," for example, is a supersonic plane which has flown at twice the speed of sound. Notice the needle nose and the thin, swept-back wings. This shape enables the plane to slice through the sound barrier, or the high-pressure area, with relative smoothness.



MOLECULES OF AIR STRIKING THE WING SURFACES HEAT THE METAL

The Heat Barrier

As higher and yet higher speeds are attained, still another problem is encountered. This is the problem of heat.

Do you remember how we defined heat in Chapter Five? We said that it is simply a matter of the speed with which the molecules are moving. When the molecules move slowly, an object is cold. When the molecules move rapidly, an object is hot.

Let us see how this affects the plane as we push it through the air faster and faster. We go far beyond the speed of sound and reach speeds of, say,

Then, a few years ago, men ran into a barrier that *blocked, for a time, any further increase in speed.* The barrier appeared at about 760 miles an hour. When a plane reached this speed it would suddenly begin to shake and bounce, as though it were hitting pockets of compressed air. Sometimes the buffeting was so violent that the wings were torn off the plane.

What happened was that the plane had reached the "sound" or "sonic" barrier, so called because it is directly related to the speed of sound. In fact, 760 miles an hour is the speed of sound at sea level. You will remember in our discussions of sound (in Chapter Fifteen) that sound travels as a series of compression waves; the molecules of air are pushed close together, and these compressed areas travel outward from the sound source.

When a plane is traveling slower than sound, the *sound waves from the plane can speed on ahead of* the plane. But when the plane increases to the speed of sound, then it keeps pace with the sound waves. At this point, the compression waves cannot get ahead of the plane. So they pile up in front of the wings and *fuselage,* or body, of the plane. In effect, a wall of high-pressure air stacks up ahead of the plane. Now, if the plane attempts to go faster, it must break through this "wall." You can

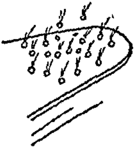


DOUGLAS SKYROCKET

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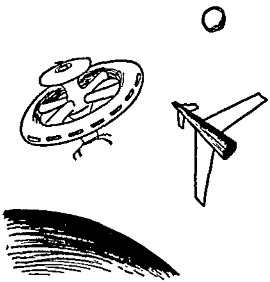
1,500 miles an hour. At this velocity, the air molecules are moving past the wings at high speed; that is, air molecules are bumping the wings very hard and often. But that is what happens to a kettle on a fire! The rapidly moving molecules from the fire bump the kettle and cause it to get hot. In the same way, the air molecules, as they bump the plane wings and fuselage, cause them to get hot.

THERE IS NO HEAT BARRIER AT VERY HIGH ALTITUDES



The faster the plane goes, the hotter the metal of the wings and body will get. The wings could get so hot at high speed that the metal would weaken and fail. This is one of the big problems of very high-speed airplanes. One suggestion is to fly the planes at very high altitudes, where there is little air to sweep over the wings and make them hot. But if there is very little air, what would give the wings enough lift to hold the plane up? Other possible solutions offered include refrigerating the wings to keep them cool, and using metals that remain strong even at very high temperatures. Of course, to refrigerate the wings effectively would require elaborate and heavy equipment, and a plane can carry only so much load after all. On the other hand, the use of metals that stay strong even when heated offers considerable possibilities.

Of course the use of rockets that will carry the plane up above the atmosphere would avoid the problem of heat—except during the time that the plane passes up through the atmosphere and when it comes down to a landing again.



Chapter Thirty

SPACE TRAVEL

YOU MAY HAVE READ stories in which the hero gets into his spaceship and "blasts off" into the outer reaches of space without a worry about fuel. Or perhaps he adjusts the controls and by means of "space-warp," or some such imaginary marvel, moves his ship through the fourth dimension to some distant galaxy in the twinkling of an eye.



Reality, however, is seldom that simple. We can do these things in our imagination, and perhaps someday our dreams will turn into reality. Meanwhile, however, we must be content with the truth about rockets, rocket fuels, and gravitational attraction.

EARLY DEVELOPMENTS

For hundreds of years rockets were scarcely more than fireworks and curiosities. Then, during the First World War (1914–1918), a young American,

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keeping abreast of other countries. We cannot afford to fall behind in the development of rocket weapons.

Beating Gravity

We would be lost without gravity. Everything would fly off the earth, including the air, water, automobiles, dogs, people, and other unattached objects. In fact, the earth itself would fly apart. Without gravity, there would be no earth, no sun, no universe. So it is fortunate that we have that attractive force between material objects which we call "gravity."



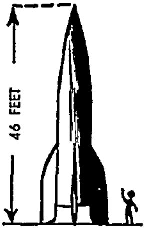
On the other hand, men who dream of shaking the dust of earth from their feet are perhaps a little annoyed with gravity. For it is gravity that they have to beat if they are to get away from the earth. After you throw a ball upward, gravity pulls it back to the earth. The harder you throw the ball, the higher it will go. How fast would you have to throw it in order to beat gravity entirely; that is, in order for the ball to keep on going and never return to the earth? You would have to throw it at a speed of 25,000 miles an hour!

Even the great pitcher Bob Feller could never fire a baseball that fast; his maximum was about 100 miles an hour. And a high-powered rifle can fire a bullet at only about 1,800 miles an hour. So you can see that we have a tremendous problem facing us if we want to send anything upward fast enough for it to escape from the gravitational

Robert H. Goddard, began to study rockets seriously.

Considerable work was done during the next 20 years. Rockets became bigger and faster, and could probe higher into the heavens. Here, at last, thoughtful men were saying, was the device that *might one day carry* men to the moon *and beyond.*

Then came the Second World War. The great dream of space flight was debased. Rockets were given the deadly job of carrying explosive charges great distances. Out of Germany roared "V-2" rockets, 46 feet long and weighing 14 tons. They were awesome weapons as they dropped at speeds of over 3,000 miles an hour upon England. Fortunately for England, the rockets were relatively inaccurate. Their control systems could not always guide them to their assigned targets, and so many of the rockets fell harmlessly into the English Channel, or into open fields.



THE V-2 WEIGHS 14 TONS

But larger, more accurate, and more deadly rocket weapons were on the drawing boards when, fortunately, the war ended. There was talk of huge rockets that could carry tons of explosives *across the Atlantic Ocean.* Rumor had it that highly developed control systems could guide these rockets with astounding accuracy.

But with war past, men began once more to think of using the rocket to escape from the earth, to journey to the moon and beyond. So research in rockets has continued. An added motive for big-time rocket research is, of course, the necessity of

eeping abreast of other countries. We cannot fford to fall behind in the development of rocket veapons.

BEATING GRAVITY

We would be lost without gravity. Everything would fly off the earth, including the air, water, automobiles, dogs, people, and other unattached objects. In fact, the earth itself would fly apart. Without gravity, there would be no earth, no sun, no universe. So it is fortunate that we have that attractive force between material objects which we call "gravity."

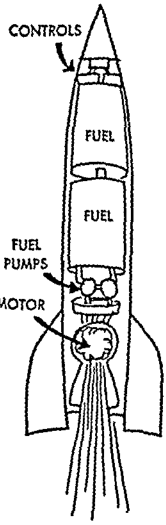


On the other hand, men who dream of shaking the dust of earth from their feet are perhaps a little annoyed with gravity. For it is gravity that they have to beat if they are to get away from the earth. After you throw a ball upward, gravity pulls it back to the earth. The harder you throw the ball, the higher it will go. How fast would you have to throw it in order to beat gravity entirely; that is, in order for the ball to keep on going and never return to the earth? You would have to throw it at a speed of 25,000 miles an hour!

Even the great pitcher Bob Feller could never fire a baseball that fast; his maximum was about 100 miles an hour. And a high-powered rifle can fire a bullet at only about 1,800 miles an hour. So you can see that we have a tremendous problem facing us if we want to send anything upward fast enough for it to escape from the gravitational

pull of the earth. If an object can be given a speed of 25,000 miles an hour, it will escape; this speed is called "escape velocity."

THE INSIDE OF A ROCKET



Rockets can do it—scientists are sure of that. As long as a rocket burns enough fuel to provide sufficient thrust, it will continue to increase in speed. The problem is to pack enough fuel into the rocket. With present fuels, scientists agree that a single rocket cannot attain escape velocity. Even if you should make a rocket that is nine-tenths fuel and only one-tenth fuel tanks, engines, housing, and so on, you could *not* attain a speed half fast enough. Such a rocket would reach a speed of less than 10,000 miles an hour before it exhausted its supply of fuel.

Even so, we can *still* beat gravity with rockets. We can do it by putting two or three rockets together, one on top of another. For example, shortly after the Second World War, American scientists mounted a small rocket—the "WAC Corporal"—on top of a V-2 rocket. This combination is called a "two-stage" rocket. The V-2 is the first "stage," the WAC Corporal the second. Let us see how this combination works. First, the V-2 rocket is fired. It takes off, carrying the WAC Corporal with it. After the two have thrust upward more than a hundred miles, the V-2 has exhausted its supply of fuel. Now it is nothing more than dead weight. Its job has been completed: it has taken the WAC Corporal on the first stage of the trip. The rocket engine of the WAC Corporal now fires. At the

same time the V-2 is detached, and begins its long fall back to the earth. But the WAC Corporal has only started. On this second stage of its trip, its rocket engines thrust it ever upward. Finally it burns the last of its fuel. This is the end of the WAC Corporal. For a few moments it probes on upward, attaining a height of perhaps 250 miles. But now it, too, must fall as gravity pulls it earthward.

If a third-stage rocket could be put on top of the second-stage rocket, scientists say the third-stage rocket could attain escape velocity. This is the way we can beat gravity—with multiple-stage rockets.



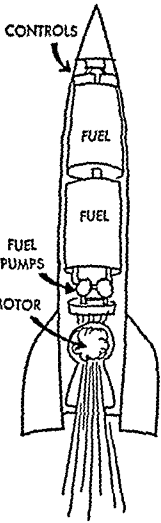
MAN-MADE MOONS

Before men take off from earth in rockets, they want to know about conditions far above earth, such as the intensity of ultraviolet radiation and cosmic rays, density of the atmosphere, temperature, presence of solid particles, etc. To find out all this, and more, scientists are working to put tiny moons, or satellites, circling in orbits 200 miles above the earth. The moons will be only a foot or so in diameter and packed with intricate instruments. These instruments can report, by radio, on conditions encountered.

The satellite requires a three-stage rocket to lift it 200 miles up in the sky. There, it will circle the earth at 18,000 miles an hour. Notice that this is below escape velocity. Gradually, over a period

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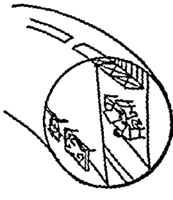
into the sky, carrying men and materials. As materials accumulate, men protected by space suits will put the space station together. The rockets will be returned to earth to be refilled and returned.

The space station must be airtight so that it can hold a breatheable atmosphere for the men who will live in it. At 1,000 miles there is practically no air at all. Also, it must be insulated against the heat of the sun and the cold of space. Without an atmosphere to protect it, the sun will heat the lighted side to temperatures of hundreds of degrees. On the dark side, temperatures will be close to absolute zero, or near −459 degrees Fahrenheit.



CUT-AWAY VIEW OF A SPACE STATION

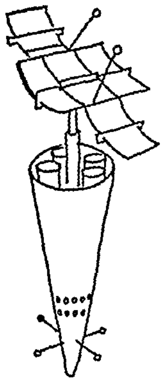
Present designs call for making the space station doughnut-shaped. It will revolve slowly like a wheel to produce a small gravitational effect. This will make the men living inside the doughnut feel more at home; for one of the possible difficulties about the project is the trouble that lack of gravity might cause men. Remember, at the space platform centrifugal force will balance gravity so that men will have no sensation of gravity at all. Thus many scientists believe that the space station must revolve so that men can rest and sleep with the feel of gravity on them.



CENTRIFUGAL FORCE WILL HOLD MEN AGAINST THE FLOORS INSIDE THE SPACE STATION

The Moon Adventure

After the space station is completed, rockets will begin bringing materials to construct the spaceships that will take men 240,000 miles to the moon. One plan calls for building three giant rocket ships. The ships must be able to carry enough fuel, food,



UNMANNED SATELLITE

of days, it will spiral back to earth because of the earth's gravitational pull. Once it hits heavier air, the air friction will turn it white-hot, and it will completely burn up, much like a meteor flashing across the heavens. But by then it will have served its purpose of telling men what conditions are like 200 miles up in the sky.

Space Stations

Armed with the knowledge that unmanned rockets and satellites have reported, men will be ready for the next stage in the great adventure of space travel—a space station. Plans call for the space station to be 1,000 miles above the earth. At this distance, the speed required to keep the station in an orbit is about 16,000 miles an hour. This is less than the speed for MOUSE, but remember this: MOUSE is to be only 200 miles from earth. Farther out, gravitational attraction is less. So at 1,000 miles, a speed of 16,000 miles an hour will keep the space station circling permanently, just as our moon circles the earth.

At this distance and speed, the two opposing forces of gravity and centrifugal force will keep a perfect balance, much like the balancing of forces that occurs when you swing a ball on a string around your hand. The string acts as the gravitational force holding the ball in an orbit, and the centrifugal force keeps the ball moving in a circle.

To build the space station, relays of three-stage rockets are planned. One by one they will be fired

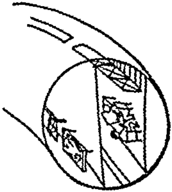
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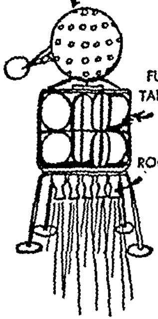
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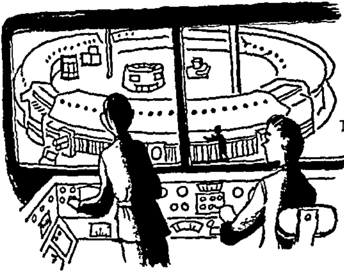
IT HAS NO STREAMLINED OUTER HULL BECAUSE IT DOES NOT PASS THROUGH AIR

water, oxygen, and other necessities for the crews. For we must remember that there is no air and water out in space and on the moon. It is proposed that one of the three ships should carry, instead of fuel, extra supplies for the return trip. This ship would be left on the moon, possibly as first living quarters for a permanent settlement.

Finally the great day will arrive. People all over the world may be able to watch the scene through television. They will see the great rocket ships hovering near the space station, loaded with crews and supplies. The giant rocket engines will flame into life, and slowly the spaceships will take off on their 240,000-mile trip to the moon. The ships are already moving at 16,000 miles an hour—the same speed as the space station; so they need to gain only a few thousand miles an hour to complete their escape from the earth's gravitational pull.

The spaceships will move faster and faster away from the space station. Finally they will be but specks, and then will vanish into the eternal blackness of space. If the ships carry television cameras, earthbound people will be able to watch the earth recede behind them, and finally, after days of travel, the moon approaching.

This exciting adventure is yet to come. Some of you reading this book may play a vital part in it, for it will take many men and women to design and build the space station and the spaceships. And some of you may be in the spaceships as they journey to the moon and return. Who will be the new Columbus of the Space Age?



Chapter Thirty-one

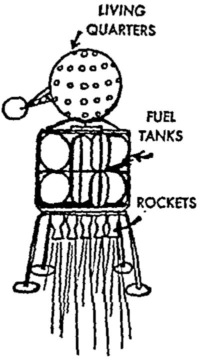
NUCLEAR SCIENCE AND ATOMIC ENERGY

IN CHAPTERS Two and Three we learned that atoms are made up of protons, neutrons, and electrons. The protons and neutrons are concentrated in the nuclei of the atoms. The number of protons determine whether the atom is oxygen, iron, copper, uranium, or some other element.

For a long time men thought that atoms were indivisible. You can break molecules down into atoms. But that, they said, is as far as you can go. You can take some of the electrons from an atom, but the core, or nucleus, of the atom is unbreakable, they explained.

As men pushed their studies of the atom further, however, they realized that this is untrue. For some atoms may throw off protons and change from one element to another. For instance an atom of radium, which has 88 protons in its nucleus, may undergo spontaneous change. It will emit 6 protons in a series of steps, to change to lead. During these steps, the radium atom also emits a great deal

water, oxygen, and other necessities for the crews. For we must remember that there is no air and water out in space and on the moon. It is proposed that one of the three ships should carry, instead of fuel, extra supplies for the return trip. This ship would be left on the moon, possibly as first living quarters for a permanent settlement.



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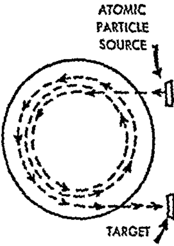
As you can see from the illustration at the top of page 179, it is a doughnut-shaped device. Inside there is a hollow ring; a vacuum pump maintains a very high vacuum in the ring. Along the ring are heavy electromagnets.

Here is how the atom smasher works: Protons, or other atomic particles, are shot into the ring. There, alternating magnetic fields from the electromagnets urge the particles on. The particles circle faster and faster, getting an additional magnetic boost with every revolution. Finally, when they are going at the desired speed, which may be well above 100,000 miles a second, they fly from the ring into a target. This target is made up of atoms to be "smashed."

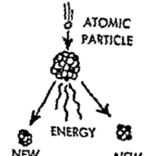
The atomic particles act differently on different kinds of atoms, depending upon the type of particles, their speeds, and the type of atoms they hit. In some cases, the target atoms are actually smashed, or broken into smaller atoms. In other cases, atomic particles may combine with target atoms to make larger, and more complex, atoms.

Fission and Fusion

When atoms split, the process is called "fission." When atomic particles enter atoms to make new, more complex atoms, the process is called "fusion." With either process energy is released—energy in huge amounts. This release of energy is the basis of atomic energy and atom bombs.



ATOM SMASHER IN ACTION

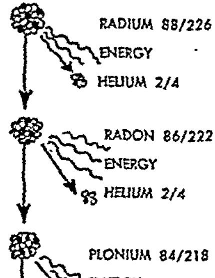


FISSION—PARTICLE SPLITS ATOM INTO NEW ELEMENTS



FUSION—PARTICLE COMBINES WITH ATOM TO FORM A NEW ELEMENT

TRANSMUTATION OF RADIUM TO LEAD



THE FIGURES TO THE RIGHT ARE NUMBERS OF PROTONS IN THE ATOMS AND ATOMIC WEIGHTS OF THE ELEMENTS

of energy in the form of radiations and heat. Only a few elements are capable of changing to different elements in this manner.

On the other hand, elements can also be changed by the addition of more protons to their nuclei. For instance, we mentioned on page 22 that men have created a whole series of new elements by bombarding atoms of uranium and other heavy elements with nuclear bullets. Such bombardments can also be used to "smash" atoms, or break them apart. In either case, whenever atoms are changed, energy is released. This release of energy, of course, is the basis of atomic energy.

Atom Smashing

The study of the insides of atoms, or of atomic nuclei, is called "nuclear science," or "nucleonics." Men have built amazing instruments in their attempts to learn more about nuclear structure. For nuclear knowledge can be put to work in many ways for the benefit of mankind. Already we have learned to split atoms in such a way as to obtain huge amounts of energy. This atomic energy is already propelling submarines and driving generators in electric power plants. And we have learned to make atoms that are unstable (in the way that radium is unstable); such unstable atoms have many uses in medicine, agriculture, and industry. We shall come back to this on a later page.

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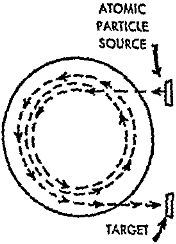
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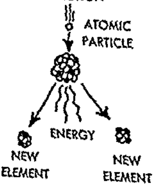
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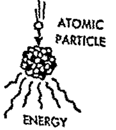
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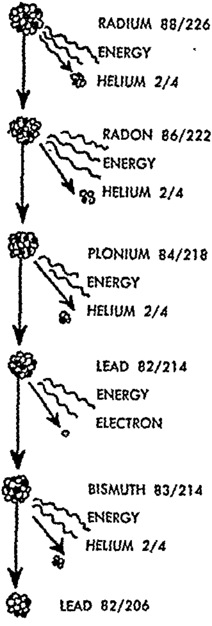


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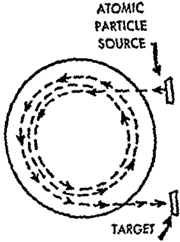
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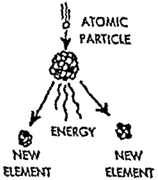
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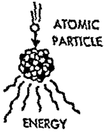
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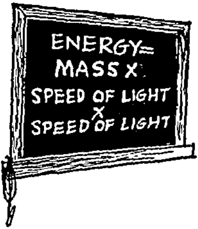
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In 1905 Albert Einstein, the famous German-Swiss scientist, formulated a theory about the amount of energy that can result from fission or fusion. This is the theory of the equivalence of mass and energy. In simple language, it means that any material substance can be converted into energy, and conversely, that energy can be changed into material substances.

Offhand you may think that this is about the same thing that goes on in ordinary combustion. But you will remember that in combustion the atoms themselves are left unchanged. When coal is burned, ash remains and the rest of the coal goes up the chimney as carbon dioxide and other gases. According to Einstein's formula, however, when a substance is converted into energy, the atoms *vanish*. They become changed into light, heat, and other electromagnetic waves, all of which are forms of energy.



Einstein's simple formula states that the energy to be obtained equals the *mass* (or weight) of the substance being converted, times the velocity of light, times the velocity of light. Or, in the form of an equation:

$$E = MC^2$$

where E is the energy, M the mass, and C the velocity of light. This formula means that one pound mass of any substance, if completely converted into energy, would produce the same amount of heat

as would be produced by the burning of 2,800,000,-000 pounds of coal!

Scientists have not learned, yet, how to convert mass completely into energy. But a partial conversion can be made, for example, by starting with one form of the element uranium. Atoms of this uranium can be made to split, or break down, into simpler atoms by the fission process. The weights of these simpler atoms are slightly less (about 0.1 per cent) than the weights of the uranium atoms. This difference represents what has been converted into energy.

When atoms can be made to combine by the fusion process, some of the mass of the atoms we start with is converted into energy. For example, if we take the nuclei of 2 hydrogen atoms (or 2 protons), and combine them with 2 neutrons, we end up with one helium atom. There is a loss in mass of about 0.75 per cent; this mass is converted into energy.

Thus you can see that, even though mass cannot be completely converted into energy, it is possible to make partial conversions; and these partial conversions will release tremendous amounts of energy.

THE FISSION PROCESS

There is one additional fact about atoms that we must mention before we can take up the story of atomic energy from fission. This fact is that not all of the atomic nuclei of an element are identical.



8 PROTONS
8 NEUTRONS
IN NUCLEUS

AN ISOTOPE OF OXYGEN



8 PROTONS
9 NEUTRONS
IN NUCLEUS

AN ISOTOPE OF OXYGEN

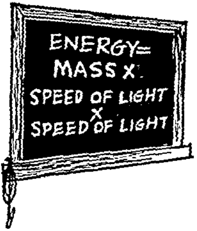


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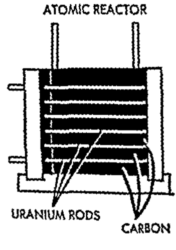


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where E is the energy, M the mass, and C the velocity of light. This formula means that one pound mass of any substance, if completely converted into energy, would produce the same amount of heat

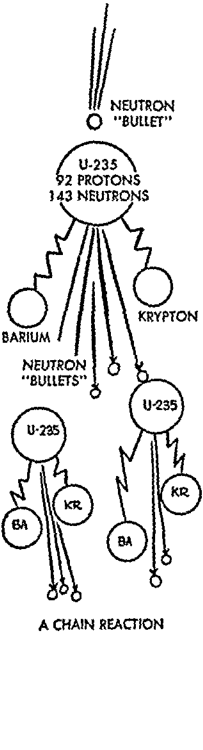
left over from the first fission will cause some of them to fission too. In fact, if there are enough U-235 atoms around, a *chain reaction* will be set up. Does this give you a clue about what goes on in an atomic, chain-reacting pile?



Atomic-power Reactors

Chain-reacting piles, or *atomic-power reactors,* contain large quantities of uranium. The uranium is carefully arranged with other materials so that the chain reaction can continue and yet be controlled. If it went on unchecked, it could cause a terrible explosion. This is the sort of process that takes place in an atom bomb: masses of U-235 are brought together so that an uncontrolled chain reaction results. All the U-235 atoms split at once, releasing fission energy in a blinding flash of radiation and heat.

The uranium used in many reactors is ordinary uranium. Only one in every 140 atoms is U-235—the rest are U-238. This mixture produces certain problems that must be solved before a chain reaction will start. For although U-235 atoms will split when they capture neutrons, U-238 atoms will not. Yet, since there are 140 times as many U-238 atoms, they will capture most of the neutrons. Thus a chain reaction will not start unless we make it possible for the U-235 atoms to capture more of the neutrons. We can do this by slowing down neutron speed. For U-238 atoms do not often cap-



A CHAIN REACTION

They may vary in the number of neutrons they carry.

These various forms of an element are called "isotopes" (ī'sō-tōps). Most elements have more than one form, or isotope. Oxygen has three (see right). Uranium has two isotopes. The more common one has 92 protons and 146 neutrons, with an atomic weight of 238. The less common isotope of uranium also has 92 protons but only 143 neutrons, and an atomic weight of 235. The two isotopes are usually referred to as "U-238" and "U-235." About one out of every 140 uranium atoms is U-235, and the rest are U-238.

The shortage of neutrons in U-235 seems to give its atoms a strange sort of instability. If a wandering neutron should happen to fly into the nucleus of a U-235 atom, the nucleus will usually split into at least two pieces. *These pieces will fly* away from each other at high speed. They contain *all of the protons and most of the neutrons* in the original U-235 atom. As an example, one piece might contain 56 protons and 82 neutrons; this piece is an atom of the element *barium* (bâr'ĭ-ŭm). The second piece might have 36 protons and 48 neutrons; this makes it an atom of the element *krypton* (krĭp'tŏn). This accounts for all the protons, but notice that there are a number of neutrons left over. These neutrons fly away in all directions.

If there should happen to be additional U-235 atoms nearby, the chances are the extra neutrons

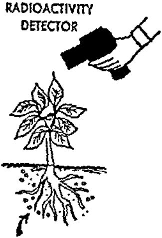
very harmful effect on living things; a person exposed to them for even a few moments will sicken and die. For this reason, atomic reactors are carefully shielded with thick walls of concrete or other material. Walls many feet thick slow and finally stop the radiations.

But there is another danger. The radiations from the fission process can so change nearby substances as to cause them, too, to give off dangerous radiations. Such substances are said to have become *radioactive* (rā'dĭ-ō-ăk'tĭv). For example, suppose that air should leak into an atomic reactor and then leak out again. The air would become radioactive and dangerous for anyone to breathe.

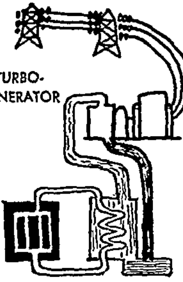


Using radioactive materials

But radioactivity can be put to good use. For example, a small amount of material made radioactive in an atomic reactor may be mixed with plant fertilizer and plants then fed with this fertilizer. Scientists, using extremely sensitive detecting devices, can then follow the radioactive fertilizer as it passes through the plant. This study helps scientists understand how plants use food.



In a similar way, radioactive materials can be used to learn how the glands and organs of our bodies function. Further, they can help doctors diagnose and cure different diseases. For example, when the *thyroid* (thī'-roid) gland, in the neck, is not functioning properly, a person may feel dull and tired, or perhaps he may become extremely nervous and excitable. By giving a patient a tiny



ATOMIC-ENERGY POWER PLANT


SUBMARINES


SHIPS


AIRPLANES


AUTOMOBILES


HOME HEATING

ture slow neutrons; however, U-235 atoms will.

To slow down neutrons, the uranium may be put into the reactor in the shape of rods, and the rods surrounded with a *neutron-slower, or moderator,* such as carbon. Now, when a U-235 atom splits and gives off several neutrons, the neutrons are slowed down as they pass through the carbon. They therefore have a far better chance of being captured by other U-235 atoms and causing them to split, too. By varying the relationship of the uranium rods and the carbon, the chain reaction can be speeded up or slowed down.

During the chain reaction, a great deal of heat is produced. This heat can be used to boil water and make steam. The steam can then be used to drive a steam turbine, which in turn can run a machine or drive an electric generator. An increasing amount of electricity is being produced by atomic energy. Someday a substantial part of the electricity we use will be made in this way.

Submarines are already being powered by atomic energy. Scientists say that ships, railroad locomotives, and even airplanes and possibly automobiles may one day make use of it. And someday, perhaps, homes will be heated from a small reactor in the basement. A major problem with smaller reactors, such as an automobile or home would use, is the radiation shielding required; this is discussed in the next paragraph.

Danger!

The fission of U-235 not only produces heat, but also dangerous radiations. These radiations have a

very harmful effect on living things; a person exposed to them for even a few moments will sicken and die. For this reason, atomic reactors are carefully shielded with thick walls of concrete or other material. Walls many feet thick slow and finally stop the radiations.



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RADIOACTIVITY DETECTOR



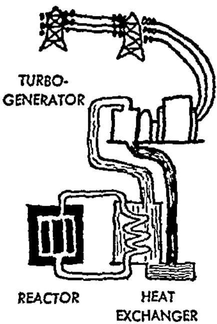
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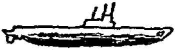


RADIOACTIVE FERTILIZER

In a similar way, radioactive materials can be used to learn how the glands and organs of our bodies function. Further, they can help doctors diagnose and cure different diseases. For example, when the *thyroid* (thī'-roid) gland, in the neck, is not functioning properly, a person may feel dull and tired, or perhaps he may become extremely nervous and excitable. By giving a patient a tiny



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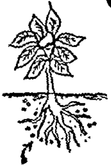
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RADIOACTIVITY DETECTOR





RADIOACTIVE FERTILIZER

Using radioactive materials

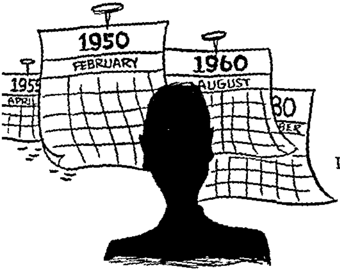
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In a similar way, radioactive materials can be used to learn how the glands and organs of our bodies function. Further, they can help doctors diagnose and cure different diseases. For example, when the *thyroid* (thī'-roid) gland, in the neck, is not functioning properly, a person may feel dull and tired, or perhaps he may become extremely nervous and excitable. By giving a patient a tiny

amount of radioactive iodine, a doctor can determine how well the thyroid gland is functioning. The thyroid absorbs the iodine at various rates, depending upon how well the gland is working.

Fusion has not, so far, been tamed. Men have made use of fusion in the terrible hydrogen bomb (the "H-bomb"). But we have been unable to slow down the process enough for any other purpose. We have already mentioned (on pages 26–27) a fusion process in which hydrogen is involved. During fusion, 2 hydrogen nuclei (or 2 protons) unite with 2 neutrons to form the nucleus of a helium atom.

To produce fusion in this manner, enormous temperatures and pressures are needed. Thus, to set off an H-bomb, a special triggering device is required. The "trigger" may be a conventional uranium-atom bomb, for example. When the H-bomb goes off, the temperatures in the fusion area soar to several million degrees. No material known to man can withstand this much heat. Thus, for the time being at least, there is no way to harness the energy of fusion. Someday, let us hope, men will work out a method of slowing down the fusion process, and of producing it on a small scale so that it can be made to do useful work. When that time arrives, mankind will have all the energy it can ever use. For hydrogen is plentiful; and with unlimited energy, there will be no limit to what men can do in science, industry, and the arts.



Chapter Thirty-two

INTO THE FUTURE

About ninety years ago, the director of the United States Patent Bureau resigned. He explained his decision by pointing out that few new inventions were being made, because there was little left to invent. In fact, he added, almost everything possible had already been invented, and the patent office might as well close its doors.

Since that time, however, there has been as much—if not more—scientific progress as in all the centuries before. Electric lights, airplanes, radio, motion pictures, automobiles, television, reactors for atomic energy—to name but a few things—have all been invented since then.

Anyone who would declare today that all the important inventions have already been made would almost surely be proved wrong before another year had passed; for new inventions and important discoveries in scientific fields are being announced all the time.

As you have read the pages of this book, you have noticed how inventions have seldom been the product of one man's genius alone. Nearly always, the man credited with the invention built upon the knowledge that other men before him had gathered together. Edison probably could not have invented his motion-picture machine or the electric light if other men had not already studied the eye, light, and electricity, and thus made available to Edison a vast fund of knowledge about them. Edison read books and studied scientific reports to learn the facts that these men had discovered; so he did not have to *rediscover* the same facts, but by using them could move ahead to make new discoveries of his own.



This, of course, is not the only example, or one of a few. It is typical of what is always taking place in the scientific world. Men of all nations and creeds have labored in their many ways to add to the world's fund of knowledge. This vast storehouse of knowledge, available in books to us all, makes it possible for men to push on further and further toward new discoveries and new marvels of scientific accomplishment.

The knowledge is there. It is yours for the reading. Who will be the Edison of tomorrow, gathering knowledge from many books, and using that knowledge as a ladder for climbing to great new discoveries and inventions? *It can be you.*

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inue numbered thousands. He, with his herd, had started for the lake upon information that there was water there. As he marched through the mouse community, he crushed faces, eyes, heads, and necks of such mice as he encountered.

Then the survivors held a convention. "We are being killed," they said, "by these lumbering elephants—curse them! If they come this way again, there will not be mice enough for seed. Besides:

> An elephant will kill you, if
> He touch; a serpent if he sniff;
> King's laughter has a deadly sting;
> A rascal kills by honoring

Therefore let us devise a remedy effective in this crisis."

When they had done so, a certain number went to the lake, bowed before the elephant-king, and said respectfully: "O King, not far from here is our community, inherited from a long line of ancestors There we have prospered through a long succession of sons and grandsons. Now you gentlemen, while coming here to water, have destroyed us by the thousand. Furthermore, if you travel that way again, there will not be enough of us for seed. If then you feel compassion toward us, pray travel another path. Consider the fact that even creatures of our size will some day prove of some service."

And the elephant king turned over in his mind what he had heard, decided that the statement of the mice was entirely logical, and granted their request.

Now in the course of time a certain king commanded his elephant-trappers to trap elephants. And they constructed a so-called water-trap, caught the king with his herd, three days later dragged him out with a great tackle made of ropes and things, and tied him to stout trees in that very bit of forest.

When the trappers had gone, the elephant-king re-

When flow
Bons mots
Composed with art,
Though fe-
Males be
Removed apart.

Now one day Spot failed to appear at the regular hour. And the others, missing him, alarmed also by an evil omen that appeared at that moment, drew the conclusion that he was in trouble, and could not keep up their spirits. Then Slow and Gold said to Swift: "Dear fellow, we two are prevented by locomotive limitations from hunting for our dear friend. We beg you, therefore, to hunt about and learn whether the poor fellow is eaten by a lion, or singed by forest fire, or fallen into the power of hunters and such creatures. There is a saying:

One quickly fears for loved ones who
In pleasure-gardens play:
What, then, if they in forests grim
And peril-bristling stay?

By all means go, search out precise news concerning Spot, and return quickly."

On hearing this, Swift flew a little distance to the edge of a swamp, and finding Spot caught in a stout trap braced with pegs of acacia-wood, he sorrowfully said: "My dear friend, how did you fall into this distress?" "My friend," said Spot, "there is no time for delay. Listen to me.

When life is near an end
The presence of a friend
Brings happiness, allying
The living with the dying.

Oh, pardon any expressions of friendly impatience I may have used in our discussions. Likewise, say to Gold and Slow in my name:

flected thus: "In what manner, or through whose assistance, shall I be delivered?" Then it occurred to him: "We have no means of deliverance except those mice."

So the king sent the mice an exact description of his disastrous position in the trap through one of his personal retinue, an elephant-cow who had not ventured into the trap, and who had previous information of the mouse community.

When the mice learned the matter, they gathered by the thousand, eager to return the favor shown them, and visited the elephant herd. And seeing king and herd fettered, they gnawed the guy-ropes where they stood, then swarmed up the branches, and by cutting the ropes aloft, set their friends free.

"And that is why I say:

> Make friends, make friends, however strong,

and the rest of it."

When Slow had listened to this, he said, "Be it even so, my dear fellow. Have no fear. In this place you are at home. Pray dismiss anxieties and behave as in your own dwelling." So they all took food and recreation at such hours as suited each, met at the noon hour in the shade of crowding trees beside the broad lake, and spent their time in reciprocated friendship, discussing a variety of masterly works on religion, economics, and similar subjects. And this seems quite natural

> *For men of sense, good poetry*
> *And science will suffice*
> *The time of dunderheads is spent*
> *In squabbling, sleep, and vice*

And again:

> A thrill
> Will fill

and learn how I have been made captive a second time, having once before suffered the woes of captivity."

"Tell me," said Gold, "how once before you suffered the woes of captivity. I am eager to learn the full detail." And Spot told the story of

SPOT'S CAPTIVITY

Long ago, when I was six months old, I used to gambol in front of all the rest, as a youngster does. Out of sheer spirits I would run far ahead, then wait for the herd. Now we deer have two gaits, called the Jump-Up and the Straightaway. Of these I knew the Straightaway, but not the Jump-Up.

While amusing myself one day, I lost touch with the herd. At this I was dreadfully worried, gazed about the horizon to learn where they might be, and discovered them ahead. Now they had avoided a snare by means of the Jump-Up; they stood in a body ahead of me, and waited, all looking at me. But I, ignorant of the Jump-Up, was caught in the hunter's snare.

While I was trying to drag it toward the herd, the hunter bound all my limbs and I fell to the ground, head foremost. And the herd of deer vanished, seeing no hope of saving me.

When the hunter came up, he did not put me to death, for pity softened his heart at the thought: "He is a fawn, fit only for a pet." Instead, he carefully took me home and gave me as a plaything to a prince, who showed his delight at seeing me by giving the hunter a generous reward.

The prince treated me kindly, providing ointments, massage, baths, food, perfumes, and salves, while my meals were appropriate and palatable. But as I was passed from hand to hand by the curious women and princes at court, I was seriously inconvenienced by petting and scratching, which did not spare neck, eye, front

If any ugly word
Was willy-nilly heard,
I pray you both, forgive—
Let only friendship live."

On hearing this, Swift replied: "Feel no fear, my dear fellow, while you have friends like us. I will return with all speed, bringing Gold to cut your bonds."

Thereupon, with his heart in a flutter, he found Slow and Gold, explained the nature of Spot's captivity, then returned to Spot, carrying Gold in his beak. Gold, for his part, on seeing the plight of his friend, sorrowfully said: "My dear fellow, you always had a wary mind and a shrewd eye. How, then, did you fall into this dreadful captivity?"

And Spot rejoined: "Why ask, my friend? Fate, you know, does what it will. As the saying goes:

What mortal flies
(However wise)
When billows rise
To fatal size
On seas of woe?

In dead of night,
Or broad daylight,
Grim fate may smite;
Ah, who can fight
An unseen foe?

You, my saintly friend, are familiar with the caprices of constraining destiny. Therefore be quick. Cut my bonds before the pitiless hunter comes."

"Have no fear," said Gold, "while I am at your side. In my heart, however, is great sorrow, which I beg you to remove by telling your story. You are guided by an eye of wisdom. How did you fall into this captivity?"

"Well," said Spot, "if you insist on hearing it, listen.

"Thus, though having suffered a previous captivity,
I am caught again through constraining destiny."

At this moment Slow joined them. For his heart was so full of love for his friend that he had followed, leaving grass, shrubs, and spear-grass crushed behind him. At sight of him, they were more distressed than ever, and Gold became their spokesman. "My dear fellow," said he, "you have done wrong in leaving your fortress to come here, since you are not able to save yourself from the hunter, while on us he cannot lay hands. For when the bonds are cut and the hunter stands near, Spot will bound away and disappear, Swift will fly into a tree, while I, being a little fellow, will find some chink to slide into. But what will you do, when within his reach?"

To this Slow listened, but he said: "Oh, do not blame me, you of all people. For

> The loss of love and loss of wealth
> Who could endure
> But for restoratives of health
> In friendship sure?

And again,

> The days when meetings do not fail
> With wise and good
> Are lovely clearings on the trail
> Through life's wild wood.
>
> The heart finds rest in telling things
> (When troubles toss)
> To honest wife, or friend who clings,
> Or kindly boss.

Ah, my dear fellow,

> The wistful glances wander,
> The wits, bewildered, ponder

hoof, hind hoof, or ear. Finally, one day in the rainy season, as the prince reclined on a couch, I observed the lightning, listened to the thunder, and, my heart wistful for my fondly remembered herd, I recited:

> When shall I follow on the herd
> Of coursing deer again?
> When brace myself against the wind
> That whistles by? Ah, when?

"Who said that?" cried the prince, and looked about him, terrified. When he saw me, he thought: "No man said it, but a deer. It is a prodigy. I am undone," and like one possessed by a devil, he tottered from the house, his garments in disarray.

Thinking himself ridden by a demon, he tempted the sorcerers and magicians with a great reward, saying: "If any free me from this torment, I will pay him no small honor."

Meanwhile, overhasty individuals were striking me with sticks, bricks, and cudgels, but—further life being predestined—I was rescued by a certain holy man who said: "Why kill the poor beast?" Furthermore, he penetrated the cause of my malady, and respectfully said to the prince: "Dear sir, in the rainy season he wistfully remembered his native herd, and therefore recited.

> When shall I follow on the herd
> Of coursing deer again?
> When brace myself against the wind
> That whistles by? Ah, when?"

On hearing this, the prince was cured of his feverish malady, returned to his normal state, and said to his men: "Douse the poor deer's head in plenty of water, and set him free in the forest he came from." And they did so.

"Thus, though having suffered a previous captivity,
I am caught again through constraining destiny."

At this moment Slow joined them. For his heart was so full of love for his friend that he had followed, leaving grass, shrubs, and spear-grass crushed behind him. At sight of him, they were more distressed than ever, and Gold became their spokesman. "My dear fellow," said he, "you have done wrong in leaving your fortress to come here, since you are not able to save yourself from the hunter, while on us he cannot lay hands. For when the bonds are cut and the hunter stands near, Spot will bound away and disappear, Swift will fly into a tree, while I, being a little fellow, will find some chink to slide into. But what will you do, when within his reach?"

To this Slow listened, but he said: "Oh, do not blame me, you of all people. For

> The loss of love and loss of wealth
> Who could endure
> But for restoratives of health
> In friendship sure?

And again:

> The days when meetings do not fail
> With wise and good
> Are lovely clearings on the trail
> Through life's wild wood.
>
> The heart finds rest in telling things
> (When troubles toss)
> To honest wife, or friend who clings,
> Or kindly boss.

Ah, my dear fellow,

> The wistful glances wander,
> The wits, bewildered, ponder

Woes come, old enmities grow hot;
Misfortunes crowd the weakest spot.

One walks at ease on level ground
Till one begins to stumble;
Let stumbling start, and every step
Is apt to bring a tumble.

And besides:

'Tis hard to find in life
A friend, a bow, a wife,
Strong, supple to endure,
In stock and sinew pure,
In time of danger sure.

False friends are common. Yes, but where
True nature links a friendly pair,
The blessing is as rich as rare.

To bitter ends
You trust true friends,
Not wife nor mother,
Not son nor brother.

No long experience alloys
True friendship's sweet and supple joys.
No evil men can steal the treasure:
'Tis death, death only, sets a measure.

"Ah, what is this fate that smites me ceaselessly? First came the loss of property; then humiliations from my own people, the result of poverty; because of gloom thereat, exile; and now fate prepares for me the loss of a friend. As the proverb says:

In truth, I do not grieve though riches flee;
Some lucky chance will bring them back to me;

In good men separated,
Whose love is unabated.

And more than that:

> Better lose your life than friends;
> Life returns when this life ends,
> Not the sympathy that blends."

At this moment the hunter arrived, bow and arrow in hand. Under his very eyes Gold cut the bonds and slipped into the before-mentioned chink. Swift flew into the air and was gone. Spot darted away.

Now when the hunter saw that the deer's bonds had been cut, he was filled with amazement and said: "Under no circumstances do deer cut their own bonds. It was through fate that a deer has done it." Then he spied a turtle on most improbable terrain, and with mixed feelings he said: "Even if the deer, with fate's help, cut his bonds and escaped, still I've got this turtle. As the saying goes:

> Nothing comes, of all that walks,
> All that flies to heaven,
> All that courses o'er the earth,
> If it be not given."

After this meditation, the hunter cut spear-grass with his knife, wove a stout rope, tied the turtle's feet tightly together, fastened the rope to his bow-tip, and started home. But when Gold saw his friend borne away, he sorrowfully said: "Ah, me! Ah, me!

> *No sooner sorrow's ocean-shore*
> *I reach in safety, than once more*
> *A bitter sorrow is my lot:*
> *Misfortunes crowd the weakest spot.*
>
> *Fresh blows are dreadful on a wound;*
> *Food fails, and hunger-pangs abound:*

And one last word:

> If birth and death did not exist
> Nor age nor fear of loved ones missed,
> If all were not so quick to perish,
> Whose life were not a thing to cherish?"

While Gold recited these grief-stricken sentences, Spot and Swift joined him and united their lamentations with his. And Gold said to them: "So long as our dear Slow is within sight, so long we have a chance to save him. Leave us, Spot. You must slip past the hunter unobserved, drop to earth somewhere near water, and pretend to be dead. Swift, you must spread your claws in the cage-work of Spot's horns, and pretend to peck out his eyes. Then that dreadful beast of a hunter, in the greedy belief that he has found a dead deer, will certainly wish to seize him, will throw the turtle on the ground, and hurry up. When his back is turned, I for my part will in a mere twinkling set Slow free to seek refuge in the water near by, his natural fortress. I myself will slide into a grass-clump. You, furthermore, must plan a second escape when the beast of a hunter is upon you." So they put this plan into practice.

Now when the hunter saw a deer as good as dead beside the water, and noticed that a crow was pecking at him, he joyfully threw the turtle on the ground, and ran for a club. As soon as Spot could tell from the tramp of feet that the hunter was close upon him, with a supreme burst of speed he swept into dense forest. Swift flew into a tree. The turtle, his fettering cord cut by Gold, scrambled to shelter in the water. Gold slipped into a grass-clump.

To the hunter it seemed a conjurer's trick. "What does it mean?" he cried in his disappointment. Then he returned to the spot where he had left the turtle, and saw the cord cut in a hundred pieces no longer than a finger's

'Tis this that hurts me—lacking riches' stay,
The best of friends relax and fall away.

And again:

Fate's artful linkage since my birth
Of evil deeds and deeds of worth
Pursues me on this present earth

Till states of mind that play and sway
And change and range from day to day,
Seem lives that strive and pass away.

Ah, there is only too much wisdom in this:

The body, born, is near its doom;
And riches are the source of gloom;
All meetings end in partings: yes,
The world is all one brittleness.

"Ah, me! Ah, me! The loss of my friend is death to me. What care I even for my own people? As the saying goes:

A foe of woe and pain and fear,
A cup of trust and feelings dear,
A pearl—who made it? Who could blend
Six letters in that name of friend?

Oh, friendly meetings!

O joy to which the righteous cling,
Machine that answers love's sole string,
Pure happiness in every breath,
Cut short by one stern exile—Death!

And once again:

Pleasant riches; friendship's course
In familiar ruts;
Enmities of men of sense—
Death abruptly cuts.

breadth. Then he perceived that the turtle had vanished like a magician, and anticipated danger for his own person. With troubled heart he made all speed out of the wood for home, casting anxious glances at the horizon.

Meanwhile the four friends, free of all injury, came together, expressed their mutual affection, took a new lease on life, and lived happily. And so

> If beasts enjoy so great a prize
> Of friendship, why should wonder rise
> In men, who are so very wise?

Here ends Book II, called "The Winning of Friends." The first verse runs:

> *The mouse and turtle, deer and crow*
> Had first-rate sense and learning; so,
> Though money failed and *means* were few,
> They quickly put their purpose through.

CROWS AND OWLS

Here, then, begins Book III, called "Crows and Owls," which treats of peace, war, and so forth. The first verse runs:

> Reconciled although he be,
> Never trust an enemy.
> For the cave of owls was burned,
> When the crows with fire returned.

"How was that?" asked the princes, and Vishnusharman told the following story.

In the southern country is a city called Earth-Base. Near it stands a great banyan tree with countless branches. And in the tree dwelt a crow-king named Cloudy with a countless retinue of crows. There he made his habitation and spent his time.

Now a rival king, a great owl named Foe-Crusher, had his fortress and his habitation in a mountain cave, and he had an unnumbered retinue of owls. This owl-king cherished a grudge, so that whenever he met a crow in his airings, he killed him and passed on. In this way his constant aggression gradually spread rings of dead crows about the banyan tree. Nor is this surprising. For the proverb says:

> If you permit disease or foe
> To march unheeded, you may know
> That death awaits you, sure if slow.

Who are seasoned conquerors,
In whose home no discords rise.

Make your peace with wicked men,
If your life endangered be;
Life, itself first made secure,
Gives the realm security.

And again:

Make your peace with him whose wont
'Tis to conquer in a fight;
Other foes will bend their necks
To you, fearful of his might,

Even with equals make your peace;
Victory is often given
Whimsically; take no risks—
Says the current saw in heaven.

Even with equals victory
Whimsically may alight.
Try three other methods first;
Only *in extremis* fight.

And yet again:

See! The bully to whose soul
Power is all, and peace is not,
Clashing with an equal foe,
Crumbles like an earthen pot.

Land and friends and gold at most
Have been won when battles cease:
If but one of these should fail,
It is best to live in peace.

When a lion digs for moles
Hiding in their pebbly house,

Who are seasoned conquerors,
In whose home no discords rise.

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When a lion digs for moles
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Agreements bind them not; and soon
They show a wicked transformation.

Therefore you should, in my judgment, fight with him. You know the saying:

'Tis easy to uproot a foe
Contemning fighters, never steady,
Cruel and greedy, slothful, false,
Foolish and fearful and unready.

"But more than this—we have been humiliated by him. Therefore, if you propose peace, he will be angry and will employ violence again. There is a saying:

The truculence of fevered foes
By gentle measures is abetted:
What wise physician tries a douche?
He knows that fever should be sweated.

Conciliation simply makes
A foeman's indignation splutter,
Like drops of water sprinkled on
A briskly boiling pan of butter.

Besides, the previous speaker's point about the strength of the enemy is not decisive.

The smaller often slays the great
By showing energy and vigor:
The lion kills the elephant,
And rules with unrestricted rigor.

And more than that:

Foes indestructible by might
Are slain through some deceptive gesture,
As Bhima strangled Kichaka,
Approaching him in woman's vesture.

A warlike and ambitious king
May choose 'twixt April and
November—other months are barred—
To invade the hostile land.

For storming-parties—so the books
Prescribe—all times are fair,
If hostile forces show distress,
And lay some weakness bare.

A king should put his realm in charge
Of heroes strong and fit;
Then pounce upon the hostile land,
When spies have peopled it.

The case in hand requires, O King,
The base-change called Retreat,
Not peace nor war the foe is vile,
And very hard to beat.

"Furthermore, a recessive movement is made, says the science of ethics, with due regard to cause and effect. The point is thus expressed in poetry:

When rams draw back, their butting fiercer stings;
The crouching king of beasts more deadly springs:
So wise dissemblers, holding vengeance sure,
In dumb communion with their hearts, endure.

And once again:

A king, abandoning his realm
To foes of fighting worth,
Preserves his life, as Fight-Firm did,
And later rules the earth.

And so, to sum it up:

The weak who, struggling with the strong,
Are not too proud to fight

> Stand ever firm within,
> Resolved to do or die:
> So, living, earn renown;
> Or dead, the starry sky.

And there is a further consideration:

> The union of the weak
> A powerful bully stumps:
> The hostile blizzard spares
> The shrubs that grow in clumps.
>
> And single trees, though huge
> And posted for defense,
> May be uprooted by
> The stout wind's violence.
>
> While groves of trees, where each
> Receives and gives defense,
> Unitedly defy
> The wind's fierce violence.
>
> Just so, one man alone,
> However brave he be,
> Is scorned by foes, who soon
> Proceed to injury."

Having listened to this view likewise, the king said to Live-Long: "My worthy sir, pray express your opinion also." And Live-Long said: "O King, from among the six possibilities, I recommend alliance. Pray adopt that. For the saying goes:

> Though deft and brilliant, what good end
> Can you attain without a friend?
> The fire that seems immortal will
> Die when the fanning wind is still.

"Therefore you should stay at home and seek some competent ally, to make a counterweight against the

all is highly proper, each course in its own good time. But the present hour demands duplicity. You have heard the saying:

> You must regard with like distrust
> Both peace and warlike measures; must
> Seek through duplicity your goal,
> With powerful foes of evil soul.

"In this way those who themselves trust nobody and have a single eye to self-interest can win the trust of an enemy and easily destroy him. For the saying goes:

> Shrewd enemies will cause a foe
> Whom they would ruin, first to grow:
> The flow of mucus by molasses
> Is first increased, but later passes.

And again:

> To foe, to false friend, to female
> (Particularly her for sale)
> The man so simple as to give
> Straightforward conduct, does not live.
>
> Proceed in pure straightforwardness
> With Brahmans, with the gods no less,
> With teachers, with yourself; but treat
> All other creatures to deceit.
>
> A hermit mastering his soul
> May see life simple, see it whole;
> Not those who thirst for carnal things,
> Nor, most particularly, kings.

And so.

> Strong through duplicity, you will
> Preserve your habitation still,
> For death will prove a friend in need,
> To crush a foe possessed by greed.

"Now for details. The functionaries in the hostile camp are—the counselor, the chaplain, the commander-in-chief, the crown prince, the concierge, the superintendent of the gynecæum, the adviser, the tax-collector, the introducer, the master of ceremonies, the director of the stables, the treasurer, the minister for elephants, the assessor, the war-minister, the minister for fortifications, the favorite, the forester, and so forth. By sowing intrigue among these the enemy is subdued. In one's own camp the functionaries are—the queen, the queen-mother, the chamberlain, the florist, the lord of the bedchamber, the chief of the secret service, the star-gazer, the court physician, the purveyor of water, the purveyor of spices, the professor, the life guard, the quartermaster, the bearer of the royal umbrella, and the geisha. It is by way of these that ruin befalls one's own party. As the saying goes:

> Professor, star-scout, and physician
> Find flaws within your home position:
> The madman and snake-charmer know
> Points vulnerable in the foe."

"Father," said Cloudy, "what is the origin of the deadly feud between crows and owls?"

And Live-Strong answered, "Listen. I will tell you

HOW THE BIRDS PICKED A KING

Once upon a time the bird-clans gathered for consultation. There were swans and cranes and nightingales; there were peacocks, plovers, and owls; there were doves and pigeons and partridges; there were bluejays, vultures, skylarks; there were demoiselles and cuckoos and woodpeckers and many others.

And they said, "We have in Garuda a king, to be sure. But he is ever intent on serving holy Vishnu, and pays no heed to us. What is the good of a sham king? He does

lief map of the seven continents, oceans, and mountains. A tiger-skin was spread. Golden jars were filled with five twigs, blossoms and grains; oblations were prepared; the most eminent bards chanted poetry. Furthermore, Brahmans, skilled in reciting the four Vedas, also chanted, while maidens sang songs, sweet holiday songs being their specialty. In the forefront was prepared a vessel of consecrated rice set off with white mustard, parched grain, rice-grains, yellow pigment, wreaths of flowers, conch shells, and so forth. The materials for lustration ceremonies were provided, and holiday drums rumbled. In the midst of a consecrated spot strewn with potash stood the lion-throne, adorned by the person of the owl as he waited the anointing

At that moment a crow came into the assembly from nobody knew where, announcing his entrance with a raucous caw And he thought: "Well, well! What means this gathering of all the birds, and this great festival?"

But when the birds saw him, they whispered together: "He is the shrewdest of the birds, they say. So let us have a speech from him, too For the proverb says:

> Of men, the barber smartest is:
> The jackal, of the beasts;
> The crow is cleverest of birds;
> The White-Robe, of the priests.

And besides.

> Concerted counsels of the wise,
> If heedfully thought through,
> Will never founder, being sound
> From every point of view."

So the birds said to the crow: "You know, the birds have no king They have therefore decided unanimously to anoint this owl as their supreme monarch. Please express your opinion also. You come in the nick of time."

HOW THE RABBIT FOOLED THE ELEPHANT

In a part of a forest lived an elephant-king named Four-Tusk, who had a numerous retinue of elephants. His time was spent in protecting the herd.

Now once there came a twelve-year drought, so that tanks, ponds, swamps, and lakes went dry. Then all the elephants said to the lord of the herd: "O King, our little ones are so tortured by thirst that some are like to die, and some are dead. Pray devise a method of removing thirst." So he sent in eight directions elephants fleet as the wind to search for water.

Now those who went east found beside a path near a hermitage a lake named Lake of the Moon. It was beautiful with swans, herons, ospreys, ducks, sheldrakes, cranes, and water-creatures. It was embowered in flowering sprays of branches drooping under the weight of various blossoms. Both banks were embellished with trees. It had beaches made lovely by sheets of foam born of the splashing of transparent waves that danced in the breeze and broke on the shore. Its water was perfumed by the ichor juice that oozed from elephant-temples washed clean of bees; for these flew up when the lordly creatures plunged. It was ever screened from the heat of the sun by hundreds of parasols in the shape of the countless leaves of trees on its banks. It gave forth deep-toned music from uncounted waves that turned aside on meeting the plump legs, hips, and bosoms of mountain maidens diving. It was brimming with crystal water, and beautified with thickets of water lilies in full bloom. Why describe it? It was a segment of paradise.

When they saw this, they hastened back to report to the elephant king.

So Four-Tusk, on hearing their report, traveled with them by easy stages to the Lake of the Moon. And finding a gentle slope all around the lake, the elephants plunged

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So Four-Tusk, on hearing their report, traveled with them by easy stages to the Lake of the Moon. And finding a gentle slope all around the lake, the elephants plunged

> The envoy binds; he loosens what is bound;
> Through him success in war, if found, is found.

And if you go, it is as if I went myself. Because, if you

> Speak what lies in your commission,
> Speak with careful composition,
> Grammar and good ethics seeking,
> 'Tis as if myself were speaking.

And again:

> This is, in brief, the envoy's care:
> An argument to fit the facts
> And sound results, so far as speech
> May be translated into acts.

"Depart then, dear friend. And may the office of envoy prove a second guardian angel to you."

So Victory departed and espied the elephant-king in the act of returning to the lake. He was surrounded by thousands of lordly elephants, whose ears, like flowering branches, were swaying in a dignified dance. His body was dappled with masses of pollen from his couch made of twigs from the tips of branches of flowering cassia trees; so that he seemed a laden cloud with many clinging lightning flashes. His trumpeting was as deep toned and awe inspiring as the clash of countless thunderbolts from which in the rainy season piercing flashes gleam. He had the glossy beauty of leaves in a bed of pure blue lotuses. His twisting trunk had the charm of a perfect snake. His presence was that of an elephant of heaven. His two tusks, shapely, smooth, and full, had the color of honey. Around his entire visage rose a charming hum from swarms of bees drawn by the fragrant perfume of the ichor juice that issued from his temples.

And Victory reflected: "It is impossible for folk like me to come too near. Because, as the proverb puts it:

only creature in the world who does not know the rabbit in the moon. But what is gained by much speaking? Desist from such actions, or great disaster will befall you at my hands. But if from this hour you desist, great distinction will be yours; for your body will be nourished by my moonlight, and with your companions you shall pursue your happy, carefree fancies in this forest. In the alternative case, my light shall be withheld, your body will be scorched by summer heat, and you with your companions will perish.'"

On hearing this, the elephant-king felt his heart stagger, and after long reflection he said: "It is true, sir. I have sinned against the blessed Moon. Who am I that I should longer contend with him? Pray point out to me, and quickly, the way that I must travel to win the blessed Moon's forgiveness."

The rabbit said: "Come, sir, alone. I will point it out." So he went by night to the Lake of the Moon, and showed him the *moon reflected in the water*. There was the brilliant, quivering disk, of lustrous loveliness, surrounded by planets, the Seven Sages, and hosts of stars, all dancing in the reflection of heaven's broad expanse. And its circle was complete, with the full complement of digits.

Seeing this, the elephant said: "I purify myself and worship the deity," and he dropped upon the water a trunk that two men's arms might have encircled. Thereby he disturbed the water, the moon's disk danced to and fro as if mounted on a whirling wheel, and he saw a thousand moons.

Then Victory started back in great agitation, and said to the elephant king: "Woe, woe to you, O King! You have doubly enraged the Moon." The elephant said: "For what reason is the blessed Moon angry with me?"

"Because," said Victory, "you have touched this water." So the elephant king, with drooping ears, bowed his head to the very earth in deep obeisance, in order to win

is caught in some trap, or has even been killed." And many days passed while I grieved in this way.

Now one evening a rabbit named Speedy made himself at home in the partridge's old nest in the hole. Nor did I say him nay, for I despaired of seeing the partridge again.

However, one fine day the partridge, who had grown extremely plump from eating rice, remembered his old home and returned. This, indeed, is not to be wondered at.

> No mortal has such joy, although
> In heaven's fields he roam,
> As in his city, in his land,
> And in his humble home.

Now when he saw the rabbit in the hole, he said reproachfully: "Come now, rabbit, you have done a shabby thing in occupying my apartment. Please begone, and lose no time about it."

"You fool!" said the rabbit, "don't you know that a dwelling is yours only while you occupy it?" "Very well, then," said the partridge, "suppose we ask the neighbors. For, to give you a legal quotation,

> For ownership of cisterns, tanks,
> Wells, groves, and houses, too,
> The neighbors' testimony goes—
> Such is the legal view.

And again:

> When house or field or well or grove
> Or land is in dispute,
> A neighbor's testimony is
> Decisive of the suit."

Then the rabbit said, "You fool! Are you ignorant of the consecrated tradition which says:

At holy shrines some saints are found
  Quite capable of guzzling."

Upon hearing this, Curd-Ear, whose manner of life had been assumed for the purpose of making an easy livelihood, desired to win their confidence. He therefore gazed straight at the sun, stood on his hind-legs, lifted his fore-paws, blinked his eyes, and in order to deceive them by pious sentiments, delivered the following moral discourse. "Alas! Alas! All is vanity. This fragile life passes in a moment. Union with the beloved is an empty dream. Family endearments are a conjurer's trick. But for the moral law, there would be no escape. Oh, listen to Scripture!

Each transitory day, O man,
  To moral living give,
Else, like the blacksmith's bellows, you
  Suck air, but do not live.

And furthermore:

Non-moral learning is a curse,
  A dog's tail, nothing less,
That does not save from flies and fleas,
  Nor cover nakedness.

And yet again:

A rotten ear among the wheat,
  Among the birds a bat,
Is he who spurns the moral law:
  The merest living gnat.

The flowers and fruit are better than the tree:
Better than curds is butter said to be;
Better than oil-cake, oil that trickles free,
Better than mortal man, morality.

The praise of constant steadfastness
  Some wise professors sing:

> Suppose beside your neighbor you
> For ten long years abide,
> What weight have learnèd arguments?
> Eyewitnesses decide.

Fool! Fool! Did you never hear the dictum of the sage Narada?

> The title to possession is
> A ten years' habitation
> With men But with the birds and beasts
> Mere present occupation.

"Hence, even supposing this apartment to be yours, still it was unoccupied when I moved in, and now it is mine."

"Well, well!" replied the partridge, "if you appeal to consecrated tradition, come with me, and we will consult the specialists. It shall be yours or mine according to their decision." "Very well," said the other, and together they started off to have their suit decided. I, too, was at their heels, out of curiosity "I will just see what comes of all this," I said to myself.

Now they had not traveled far when the rabbit asked the partridge. "My good fellow, who is to pass judgment on our disagreement?" And the partridge answered: "On a sand bank by the sacred Ganges—where there is sweet music from the dancing waves that intercross and break when the water is swept by nimble breezes—there dwells a tomcat whose name is Curd Ear. He abides unshaken in his vow of penance and self-denial, and character has begotten compassion."

But when the rabbit spied the cat, his soul staggered with terror, and he said. "No, no! He is a seedy rascal! You must have heard the proverb:

> Oh, never trust a rogue for all
> His pharisaic puzzling:

At holy shrines some saints are found
Quite capable of guzzling."

Upon hearing this, Curd-Ear, whose manner of life had been assumed for the purpose of making an easy livelihood, desired to win their confidence. He therefore gazed straight at the sun, stood on his hind-legs, lifted his fore-paws, blinked his eyes, and in order to deceive them by pious sentiments, delivered the following moral discourse. "Alas! Alas! All is vanity. This fragile life passes in a moment. Union with the beloved is an empty dream. Family endearments are a conjurer's trick. But for the moral law, there would be no escape. Oh, listen to Scripture!

Each transitory day, O man,
To moral living give;
Else, like the blacksmith's bellows, you
Suck air, but do not live.

And furthermore:

Non-moral learning is a curse,
A dog's tail, nothing less,
That does not save from flies and fleas,
Nor cover nakedness.

And yet again:

A rotten ear among the wheat,
Among the birds a bat,
Is he who spurns the moral law:
The merest living gnat.

The flowers and fruit are better than the tree;
Better than curds is butter said to be;
Better than oil-cake, oil that trickles free;
Better than mortal man, morality.

The praise of constant steadfastness
Some wise professors sing;

> If he who cuts down trees or cattle,
> Or makes a bloody slime in battle,
> Should thereby win to heaven—well,
> Who (let me ask you) goes to hell?

"No, no. I shall eat nobody. However, I am somewhat old and do not readily distinguish your voices from a distance. So how am I to determine winner and loser? In view of this, pray draw near and make me acquainted with the case. Then I can pronounce a judgment that discriminates the essence of the matter, and thus causes no impediment in my march to the other world. You know the stanza:

> If any man, from pride or greed,
> Timidity or wrath,
> Judge falsely, he has set his foot
> On hell's down sloping path.

And again:

> Who wrongs a sheep, slays kinsmen five;
> Who wrongs a cow, slays ten;
> A hundred die for maidens wronged;
> A thousand die for men.

"Therefore confide in me and speak clearly at the edge of my ear."

Why spin it out? That seedy rogue won their trust so fully that both drew near him. Then, of course, he seized them simultaneously, one with his paw, the other with the saw of his teeth. And when they were dead, he ate them both.

"And that is why I say:

> A seedy umpire is not very . . . .

and the rest of it.

"Just so, you, too, being blind at night, if you take as overlord this seedy fellow who is blind in the daytime,

You would not swallow poison down
Because a doctor lives in town.

No man of sense vituperates
Another, while the public waits;
For even truth should be concealed,
If causing sorrow when revealed.

And finally:

Reflect with many a chosen friend;
Reflect alone, and to the end;
Then act. You are intelligent,
And fame's and wealth's recipient."

After these reflections, the crow also left the spot.

"For this cause, my son, we have an inherited feud with the owls."

"Father," said Cloudy, "what should we do under the circumstances?" And Live-Strong answered: "Even in these circumstances there is an effective procedure other than the six expedients. This I will adopt, and will myself lead the way to conquer the enemy. I will deceive them and put them in a fatal situation. For the saying goes:

The strong, deft, clever rascals note,
Who robbed the Brahman of his goat."

"How was that?" asked Cloudy And Live-Strong told the story of

THE BRAHMAN'S GOAT

In a certain town lived a Brahman named Friendly who had undertaken the labor of maintaining the sacred fire. One day in the month of February, when a gentle breeze was blowing, when the sky was veiled in clouds and a drizzling rain was falling, he went to another vil-

Then the Brahman spoke in anger: "Are you blind, man? You call a goat a calf." And the rogue said: "Holy sir, do not be angry. I spoke in ignorance. Do as you will."

But when he had walked only a little farther through the forest, the third rogue, changing his dress, met him and said: "Sir, this is most improper. You are carrying a donkey on your shoulder. Yet the proverb tells you:

> If you should touch an ass—be it
> In ignorance or not—
> You needs must wash your clothes and bathe,
> To cleanse the sinful spot.

Pray drop this thing, before another sees you."

So the Brahman concluded that it was a goblin in quadruped form, threw it on the ground, and made for home, terrified. Meanwhile, the three rogues met, caught the goat, and carried out their plan.

"And that is why I say:

> The strong, deft, clever rascals note,

and the rest of it.

"Moreover, there is sound sense in this:

> Is any man uncheated by
> New servants' diligence,
> The praise of guests, the maidens' te
> And roguish eloquence?

Furthermore, one should avoid a quarrel with a crowd, though the individuals be weak. As the verse puts it:

> Beware the populace enraged;
> A crowd's a fearsome thing:
> The ants devoured the giant snake
> For all his quivering."

fortress is of simple construction, without egress at the rear. For the saying goes:

> A fort must have for egress, say
> The specialists, a gap;
> If this be lacking, it is not
> A fortress, but a trap.

Nor should you feel any pity for me. For the proverb says:

> Pet and pamper servants well;
> Love them as you love your life:
> Yet consider them as dry
> Tinder in the hour of strife.

Nor must you balk me in my design. For once more:

> Cherish servants like yourself;
> Guard them as you guard your life
> Every day for one sole day,
> When you meet your foe in strife."

With these words he started a sham fight with the king. And Cloudy's retinue, seeing Live-Strong jabber with unbridled license at the king, started up to kill him. But Cloudy said: "Out of my path, you. I take upon myself the chastisement of this traitorous scoundrel." With this he pounced upon him, pecked at him gently, smeared him with blood (which he had provided), and departed with his retinue for Antelope Mountain, as Live-Strong had recommended.

At this juncture the owl's consort, acting as spy for the enemy, went and reported in detail to the owl king the disgrace of Cloudy's prime minister. And the owl king, informed of the occurrence, started with his retainers at sundown on a crow-hunt. And he said: "Hasten, friends, hasten! The enemy is panic-stricken, is in

fortress. Whereupon I said: 'You should not march against him. For they are strong, and we are weak. Now the proverb advises those who wish to thrive:

> Do not, even in thought, offend
> Stronger foes who will not bend;
> They will feel no loss or shame.
> You will die, a moth in flame.

You should seek peace by paying him tribute.' When he heard this, he was made furious by rascally advisers, suspected me of being a partisan of yours, and reduced me to this state. Therefore your royal feet are now my sole refuge. In a word, so long as I can stir, I will conduct you to his abode, and cause the total destruction of the crows."

On hearing this, Foe-Crusher took counsel with the counselors who had served his father and his grandfather. They were five in number, and their names were Red-Eye, Fierce-Eye, Flame-Eye, Hook-Nose, and Wall-Ear.

So first he questioned Red-Eye: "My worthy sir, what is to be done under the circumstances?" And Red-Eye said: "O King, what is there to consider here? Kill him without hesitation. For the proverb says:

> Kill a weakling, lest he grow
> Hard to smite;
> Later, with augmented power
> He will fight.

Besides, you know how common people say: 'A lost chance brings a curse.' And again:

> He who will not when he may,
> When he will, he shall have nay.

And this too:

> The lighted funeral pile you may
> Break up and fling apart,

boy died at once. And the relatives cremated him on a woodpile near the field.

On the second day the father returned. And learning from his relatives the cause of his son's death, he found the facts as stated. And he said:

> Be generous to all that lives;
> Receive the needy guest:
> If not, your own life fades away
> Like swans from lotus nest.

"How was that?" asked the men. And the Brahman told the story of

THE UNSOCIAL SWANS

There was once a king named Gay-Chariot in a certain place. He owned a lake named Lotus Lake, which his soldiers guarded carefully. For many golden swans lived there, and they gave one tail-feather apiece every six months.

Now to that lake came a great bird, all of gold. And they told him: "You cannot live among us. For we have rented this lake at the rate of a tail-feather for six months." And so, to cut a long story short, a dispute arose.

Then the great bird sought the king's protection, saying: "O King, those birds ask: 'What will our king do? We give lodging to nobody.' And I said: 'You are not very polite. I will go and tell the king.' This is the situation. The king must decide."

Then the king said to his men: "Go, you. Kill all the birds and bring them here at once." And they started immediately, obeying the king's command.

Now one old bird saw the king's men with clubs in their hands, and he said: "Well, kinsmen, this is rather unpleasant. We must all hang together. Let us fly up and away." And they did so.

They all renounced him; he had made
Them do so by his horrid trade.

For you know

The dreadful wretches bringing death
On those who love their living breath,
With natural repulsion (like
Fierce serpents) fill before they strike.

To snare, to imprison, and to drub
He took a net, a cage, a club,
And wandering daily in the wood,
He brought all creatures harm, not good

While he was in the wood one day,
The sky grew black with clouds straightway;
So wild the wind, so fierce the rain,
It seemed the world dissolved in pain.

Then, as the heart within him quivered,
And every limb grew numb and shivered,
He sought where might a refuge be,
And chanced to come upon a tree.

Now as he rested, near and far
In sudden-clearing skies, each star
Shone bright; and he had wit to pray:
"O Lord, be kind to me today."

There was a dove upon the tree
Whose nest was in a cavity;
And since his wife was absent long,
He grieved for her in mournful song:

"The wind and rain were very great,
And my beloved wife is late
In coming home. When she is not
At home, home is an empty spot.

Will see his merit borne away,
And for the other's sins will pay.

'Oh, let no hate against him rise
Who caged the wife you idolize:
It is my sins of former lives
That, fateful, hold me in the gyves.

For well you know:

"Disease, and poverty, and pain,
With woe that prison brings amain,
Are all the fruit of one sole tree,
Our own, our past iniquity.

"Abandon, therefore, thoughts of hate
Deriving from my captive state;
On virtue set your heart; and pay
This man such honor as you may."

On listening to his darling, who
Seemed virtue-woven through and through,
An unknown courage fired the dove;
He gave the fowler words of love.

"A hearty welcome, sir, to you;
What for your service may I do?
No more let anxious fancies roam,
For here with me you are at home."

In answer to his kindly words
Replied the murderer of birds:
"Well, dove, the cold is in me still;
Give me a remedy for chill."

The dove then brought a bonfire's sole
Surviving ember—one live coal,
And where a pile of dry leaves lay,
He kindled it to fire straightway.

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Surviving ember—one live coal,
And where a pile of dry leaves lay,
He kindled it to fire straightway.

The soul commits the sin; and late
Or soon, the soul must expiate.

"My thoughts are evil; my desire
Is ever set on what is dire:
It needs but little wit to tell
I steer my course for ghastly hell.

"A moral lesson let me draw
From what my savage spirit saw.
The high-souled dove, that I may eat,
Has sacrificed himself for meat.

"Henceforth let all enjoyment be
An unfamiliar thing to me;
I'll share the shallow water's fate
In August; will evaporate.

"Cold, wind, and heat I will embrace,
Grow thin and dirty, form and face,
Will fast by every method known,
Seek virtue, perfect and alone."

The fowler then apieces tore
Club, peg, net, cage—and what is more,
Set free the wretched female dove
Who sorrowed for her perished love.

But she, released from clutches dire,
Beheld her husband in the fire:
Whereat she gave expression so
To thoughts of horror and of woe:

"My lord! My love! What shall I do
With life that drags apart from you?
What profit has a wretched wife,
Without a husband, of her life?

Having listened to this, Foe-Crusher asked Flame-Eye: "What is your opinion, sir, things standing as they do?" And Flame-Eye said:

> "She who always shrank from me
> Hugs me to her breast.
> Thank you, benefactor! Take
> What you like the best."

And the thief replied:

> "Nothing here that I should like;
> Should I want a thing,
> I'll return if she does not
> Passionately cling."

"But," asked Foe-Crusher, "who is she that does not cling? And who is the thief? I should like to hear this one in detail." And Flame-Eye told the story of

THE OLD MAN WITH THE YOUNG WIFE

There was once an aged merchant in a certain town, and his name was Lovelorn. To such an extent had love clouded his reason that, when his wife died, he gave much money in order to marry the daughter of a penniless shopkeeper. But the girl was heartbroken and could not bear to look at the old merchant. This, indeed, might have been anticipated.

> The silvered head will sue in vain,
> A maiden's love beseeching:
> The maid, despising it, is fain
> To flee afar with screeching;
> Like Hangman's Well it causes pain,
> Where dead men's bones are bleaching.

And furthermore:

> Slow, tottering steps the strength exhaust;
> The eye unsteady blinks;

And Hook-Nose answered: "O King, he should not be killed. For

> From enemies expect relief,
> If discord pierce their host;
> Thus life was given by the thief
> And cattle by the ghost."

"How was that?" asked Foe-Crusher. And Hook-Nose told the story of

THE BRAHMAN, THE THIEF, AND THE GHOST

There was once a poor Brahman in a certain place. He lived on presents, and always did without such luxuries as fine clothes and ointments and perfumes and garlands and gems and betel-gum. His beard and his nails were long, and so was the hair that covered his head and his body. Heat, cold, rain, and the like had dried him up.

Then someone pitied him and gave him two calves. And the Brahman began when they were little and fed them on butter and oil and fodder and other things that he begged. So he made them very plump.

Then a thief saw them and the idea came to him at once: "I will steal these two cows from this Brahman." So he took a rope and set out at night. But on the way he met a fellow with a row of sharp teeth set far apart, with a high bridged nose and uneven eyes, with limbs covered with knotty muscles, with hollow cheeks, with beard and body as yellow as a fire with much butter in it.

And when the thief saw him, he started with acute fear and said: "Who are you, sir?"

The other said: "I am a ghost named Truthful. It is now your turn to explain yourself."

The thief said: "I am a thief, and my acts are cruel. I am on my way to steal two cows from a poor Brahman."

And Hook-Nose answered: "O King, he should not be killed. For

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Having listened to this opinion, the king asked Wall-Ear: "What is your view, sir? Tell me." And Wall-Ear said: "O King, he certainly should not be killed. For if you spare his life, you two may well grow fond of each other, and spend the time pleasantly. There is a saying:

> Be quick with mutual defense
> In honest give-and-take;
> Or perish, like the ant-hill beast
> And like the belly-snake."

"How was that?" asked Foe-Crusher. And Wall-Ear told the story of

THE SNAKE IN THE PRINCE'S BELLY

In a certain city dwelt a king whose name was God-like. He had a son who wasted daily in every limb because of a snake that used his belly as a home instead of an ant-hill. So the prince became dejected and went to another country. In a city of that country he begged alms, spending his time in a great temple.

Now in that city was a king named Gift who had two daughters in early womanhood. One of these bowed daily at her father's feet with the greeting: "Victory, O King," while the other said: "Your deserts, O King."

At this the king grew angry, and said: "See, counselors. This young lady speaks malevolently. Give her to some foreigner. Let her have her own deserts." To this the counselors agreed, and gave the princess, with very few maid-servants, to the prince who made his home in the temple.

And she was delighted, accepted her husband like a god, and went with him to a far country. There by the edge of a tank in a distant city she left the prince to look after the house while she went with her maids to buy butter, oil, salt, rice, and other supplies. When her shopping was done, she returned and found the prince with

And again:

It argues utter want of sense
To pardon obvious offense:
The carpenter upon his head
Took wife and him who fouled his bed."

"How was that?" asked the counselors, and Red-Eye told the story of

THE GULLIBLE CARPENTER

There was once a carpenter in a certain village. His wife was a whore, and reputed to be such. So he, desiring to test her, thought: "How can I put her to the test? For the proverb says:

Fire chills, rogues bless, and moonlight burns
Before a wife to virtue turns.

"Now I know from popular gossip that she is unfaithful. For the saying goes:

All things that are not seen or heard
In science or the Sacred Word,
All things in interstellar space
Are known among the populace."

After these reflections, he said to his wife: "Tomorrow morning, my dear, I am going to another village, where I shall be detained several days. Please put me up a nice lunch." And her heart quivered when she heard this: she eagerly dropped everything to make delicious dishes, almost pure butter and sugar. In fact, the old saw was justified:

When lowering clouds
Shut in the day,
When streets are mired
With sticky clay,

also know the remedy. Is there any means of making my husband live a hundred years?' And the goddess replied: 'Indeed there is—a remedy depending on you alone.' Of course I said: 'If it cost my life, pray tell me, and I will do it.' Then the goddess said: 'If you go to bed with another man, and embrace him, then the untimely death that threatens your husband will pass to him. And your husband will live another hundred years.' For this purpose I invited you. Now do what you had in mind. The words of a goddess must not be falsified—so much is certain." Then his face blossomed with noiseless laughter, and he did as she said.

Now the carpenter, fool that he was, felt his body thrill with joy on hearing her words, and he issued from under the bed, saying: "Bravo, faithful wife! Bravo, delight of the family! Because my heart was troubled by the gossip of evil creatures, I pretended a trip to another village in order to test you, and lay hidden under the bed. Come now, embrace me!"

With these words he embraced her and lifted her to his shoulder, then said to the fellow: "My dear and honored sir, you have come here because my good deeds earned this happiness. Through your favor I have won a full hundred years of life. You, too, must mount my shoulder."

So he forced the fellow, much against his will, to mount his shoulder, and then went dancing about to the doors of the houses of all his relatives.

"And that is why I say:

> It argues utter want of sense
> To pardon obvious offense. . . .

and the rest of it.

"We are certainly uprooted and undone. For the proverb is right in saying:

the roar of the waters that broke on the rugged, rocky shore. On the bank was a hermitage crowded with holy men devoting their time to the performance of sacred rites—chanting, self-denial, self-torture, study, fasting, and sacrifice. They would take purified water only, and that in measured sips. Their bodies wasted under a diet of bulbs, roots, fruits, and moss. A loin-cloth made of bark formed their scanty raiment.

The father of the hermitage was named Yajnavalkya. After he had bathed in the sacred stream and had begun to rinse his mouth, a little female mouse dropped from a hawk's beak and fell into his hand. When he saw what she was, he laid her on a banyan leaf, repeated his bath and mouth rinsing, and performed a ceremony of purification. Then through the magic power of his holiness, he changed her into a girl, and took her with him to his hermitage.

As his wife was childless, he said to her: "Take her, my dear wife. She has come into life as your daughter, and you must rear her carefully." So the wife reared her and spoiled her with petting. As soon as the girl reached the age of twelve, the mother saw that she was ready for marriage, and said to her husband: "My dear husband, how can you fail to see that the time is passing when your daughter should marry?"

And he replied, "You are quite right, my dear. The saying goes:

> Before a man is gratified,
> Three gods must treat her as a bride—
> The fire, the moon, the choir of heaven.
> In this way no offense is given.
>
> Holiness is the gift of fire;
> A sweet voice, of the heavenly choir;
> The moon gives purity within.
> So is a woman free from sin.

Marriage (or friendship) is secure;
But not between the rich and poor.

And finally:

Aim at seven things in marriage;
All the rest you may disparage:

"But

Get money, good looks,
And knowledge of books,
Good family, youth,
Position, and truth.

"So, if she is willing, I will summon the blessed sun, and give her to him." "I see no harm in that," said his wife. "Let it be done."

The holy man therefore summoned the sun, who appeared without delay, and said: "Holy sir, why am I summoned?" The father said. "Here is a daughter of mine. Be kind enough to marry her." Then, turning to his daughter, he said: "Little girl, how do you like him, this blessed lamp of the three worlds?" "No, father," said the girl. "He is too burning hot. I could not like him. Please summon another one, more excellent than he is."

Upon hearing this, the holy man said to the sun: "Blessed one, is there any superior to you?" And the sun replied: "Yes, the cloud is superior even to me. When he covers me, I disappear."

So the holy man summoned the cloud next, and said to the maiden. "Little girl, I will give you to him." "No," said she. "This one is black and frigid. Give me to some one finer than he."

Then the holy man asked. "O cloud, is there anyone superior to you?" And the cloud replied: "The wind is superior even to me."

So he summoned the wind, and said: "Little girl, I give you to him." "Father," said she, "this one is too fidg-

When they came to the fortress gate, Foe-Crusher said: "Come, my friends! Give this Live-Strong whatever chamber he prefers—for he wishes us well."

And Live-Strong, hearing this, reflected: "I must now devise a plan for their destruction. This is not possible if I live in their midst. For they would observe motions betraying my purpose, and would keep their eyes open. Only by remaining near the gate can I accomplish my desire."

He therefore said to the owl-king: "O King, what the king has said, is eminently right. Yet I, too, am a student of diplomacy and a well wisher. I know that even one who is loyal and pure in purpose should not dwell in the heart of a fortress. I will therefore take my place here at the fortress gate and pay daily homage, my body sanctified by the dust from your lotus feet."

To this the owl-king agreed, and his efficient caterers daily gave Live-Strong, by special command of the king, the pick of the viands. So that in a very few days he grew strong as a peacock.

But Red-Eye, seeing how Live-Strong was being pampered, was amazed, and he said to the counselors and to the king himself: "Dear me! These counselors are a pack of fools, and you, too, sir. I cannot think otherwise. Then there is the saying:

> I played the fool at first, then he
> Who had me on his tether;
> And then the king and counselor—
> We all were fools together."

"How was that?" they asked. And Red-Eye told the story of

THE BIRD WITH GOLDEN DUNG

There was once a great tree on a mountain side. On it lived a bird in whose dung gold appeared.

"And that is why I say:

> I played the fool at first, ...

and the rest of it."

But once more—for fate was hostile—they neglected Red-Eye's counsel, sound as it was, and pampered Live-Strong further with varied viands, including plenty of meat.

Then Red-Eye called together his personal adherents, and said to them privately: "The end is at hand. The welfare of our king, and his fortress, are things of the past. I have given him such counsel as an ancestral counselor should give. Let us now, for our part, seek another fortress in the mountains. For the saying goes:

> Joy comes from knowing what to dread,
> And sorrow smites the dunderhead:
> A long life through, the woods I've walked,
> But never heard a cave that talked

"How was that?" they asked. And Red-Eye told the story of

THE CAVE THAT TALKED

There was once a lion in a part of a forest, and his name was Rough-Claw. One day he found nothing whatever to eat in his wanderings, and his throat was pinched by hunger. At sunset he came to a great mountain cave and went in, for he thought: "Surely, some animal will come into this cave during the night. I will hide and wait."

Presently the owner of the cave, a jackal named Curd-Face, came to the door and began to sing: "Cave ahoy! Cave ahoo-oy!" Then after a moment's silence, he continued in the same tone: "Hello! Don't you remember how you and I made an agreement that I was to speak to

> Aid him, the downfall of a king
> Is swift and sure.

And there is sound reasoning in this:

> The shrewd discover enemies
> Disguised as friends
> In senseless counselors whose speech
> To evil tends."

After these reflections, he dropped each day one fagot from the forest into his own nest, with the ultimate purpose of setting the cave afire. Nor did the owls, poor fools, perceive that he was building up his nest in order to burn them alive. Well, there is sense in the saying:

> Cause your friends no bitter woes;
> Do not fraternize with foes:
> Friends, when lost, are friends no more;
> Enemies were lost before.

Thus, pretending to build a nest, Live-Strong constructed a woodpile at the fortress gate. Then at sunrise, when the owls became blind, he hastened away and reported to Cloudy: "My lord and king, I have prepared the enemy's cave for burning. Come with your retainers, each bringing a lighted fagot from the forest, to throw on my nest at the gate of the cave. Thus all your foes will die in torments like those in Pot-baking Hell."

At this Cloudy was delighted and said: "Father, tell me your adventures. It is long since we met." "No, my son," said Live-Strong. "This is no time for talk. Some enemy spy might possibly report my journey hither. And our blind enemy, thus informed, might make his escape. Make haste, make haste. For the proverb says:

> When speed is needful, ne'er permit
> Delay, but do it pat;

The bow of heaven, Arjun felt
To woman's bracelets yield.

The wise and strong, awaiting days
More prosperous, must grant
Obedience to wicked lords
Whose speech is adamant:
Gigantic Bhima, smoke-begrimed,
Puffing at labor, and
A ladle flourished in his fist,
Was cook in Matsya land.

The prudent, hopeful man should act
As suits an evil case,
Should steel his heart to carry through
A holy deed, or base:
Great Arjun with a calloused arm
From twanging bow divine
Effeminately danced, and saw
His tinkling girdle shine.

The wise, alert, ambitious man,
If he expect success,
Must wait on fortune, watch his step,
And curb his stateliness:
Yudhishthir king, with pilgrim's staff,
Long drew his painful breath,
Though worshiped by his brothers, grea
As War, and Wealth, and Death.

So Kunti's handsome, powerful twins,
High birth writ on their brows,
Were menials at Virata's court,
And lived by counting cows.

So queenly Draupadi, with youth's
And matchless beauty's seal,

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What glutton has not much unrest
Within himself to bear?
Whom does not fortune render proud?
Whom does not death lay low?
To whom do not possessions bring
Abundant harm and woe?

The steady forfeit glory, while
The restless forfeit friends:
The bankrupt forfeits family,
The banker, better ends:
The man of passion forfeits books,
The fawner, friendship's flower;
The king with careless counselors
Must forfeit kingly power.

"Yes, O King, I have experienced *in person* what you were kind enough to put into words: that association with the enemy is equal to the sword-blade ordeal. As the old verse puts it:

Bear even foes upon your back;
When fortune clogs
Your path, endure. The great black snake
Slew many frogs."

"How was that?" asked Cloudy. And Live-strong told the story of

THE FROGS THAT RODE SNAKEBACK

There was once an elderly black snake in a certain spot, and his name was Slow-Poison. He considered the situation from this point of view: "How in the world can I get along without overtaxing my energies?" Then he went to a pond containing many frogs, and behaved as if very dejected.

As he waited thus, a frog came to the edge of the water and asked, "Uncle, why don't you bustle about today for food as usual?"

When Slow-Poison heard this, he quivered with joy
ı every member and made haste to say: "Why, that is a
art of the curse laid on me by the Brahman. For that
eason I am greatly pleased at your command." So he ate
rogs uninterruptedly, and in a very few days he grew
trong. And with delight and inner laughter he said:

> The trick was good. All sorts of frogs
> Within my power have passed.
> The only question that remains,
> Is: How long will they last?

Water-Foot, for his part, was befooled by Slow-Poison's
plausibilities, and did not notice a thing.

At this moment another black snake, a tremendous fellow, arrived on the scene. And being amazed at the sight of Slow-Poison used as a vehicle by frogs, he said: "Partner, they are our natural food, yet they use you as a vehicle. This is repellent." And Slow-Poison said:

> I know I should not carry frogs;
> I have it well in mind;
> But I am marking time, as did
> The Brahman butter-blind.

"How was that?" asked the snake. And Slow-Poison told the story of

THE BUTTER-BLINDED BRAHMAN

There was once a Brahman named Theodore in a certain town. His wife, being unchaste and a pursuer of other men, was forever making cakes with sugar and butter for a lover, and so cheating her husband.

Now one day her husband saw her and said: "My dear wife, what are you cooking? And where are you forever carrying cakes? Tell the truth."

But her impudence was equal to the occasion, and she lied to her husband: "There is a shrine of the blessed

Then Slow-Poison, with noiseless laughter, hummed over the verse:

> The trick was good. All sorts of frogs . . . .

and the rest of it. And Water-Foot, hearing this, was conscience stricken, and wondering what he meant, inquired: "My dear sir, what do you mean by reciting that repulsive verse?" "Nothing at all," said Slow-Poison, desiring to mask his purpose. And Water-Foot, befooled by his plausible manner, failed to perceive his treachery.

Why spin it out? He ate them all so completely that not even frog seed was left.

"And that is why I say:

> Bear even foes upon your back, ...

and the rest of it. Thus, O King, just as Slow-Poison destroyed the frogs through the power of intelligence, so did I destroy all the enemy. There is much wisdom in this:

> The forest fire leaves roots entire,
> Though trunks remain a shell:
> The flooding pool of water cool
> Uproots the roots as well."

"Very true," said Cloudy. "And besides:

> This is the greatness of the great
> Whom gems of wisdom decorate:
> Despite what hurts and hinders, too,
> They see an undertaking through."

"Very true," said Live-Strong. "And once again:

> The final penny of a debt,
> The final foeman dire,

And Cloudy replied: "It is wonderful how immediate is the reward of knowing social ethics. By virtue of which you penetrated and exterminated Foe-Crusher with his retinue." Whereupon Live-Strong said:

> "Where at last you need sharp measures,
> First try gentle measures there:
> Thus the lofty, lordly tree-trunk
> Is not felled without a prayer.

"And yet, O my king, why say of a future matter either that it involves no effort or that it is not readily attainable? There is wisdom in the saying:

> Since words with actions fail to suit,
> The timidly irresolute
> Who see a thousand checks and blocks
> Turn into public laughingstocks.

Nor are thoughtful men heedless even in minor matters. For

> The negligent who say:
> 'Some day, some other day—
> The thing is petty, small,
> Demands no thought at all,'
> Are, heedless, headed straight
> For that repentant state
> That ever comes too late.

"But as for my master, who has overcome his foes, he may sleep tonight as soundly as ever he did. You know the saying:

> In houses where no snakes are found,
> One sleeps; or where the snakes are bound:
> But perfect rest is hard to win
> With serpents bobbing out and in.

slip away at last; fidgety as the bandar-log; unequilibrated as water on a lotus-leaf; mutable as the wind's path; untrustworthy as rogues' friendship; hard to tame as a serpent; gleaming but a moment like a strip of evening cloud; fragile by nature, like the bubbles on water ungrateful as the substance of man's body; lost in the moment of attainment, like the treasure of a dream And furthermore:

> Whenever kings anointed are,
> Let wit spy trouble from afar;
> Anointing-jars too often spill,
> With holy water, pending ill.

"And no man in the wide world is beyond the clutch of pending ill. As the poet sings:

> Remember Rama, wandering far;
> Remember Nala's sinking star;
> With Bali's bonds, the Vrishnis' tomb,
> And Lanka's monster-monarch's doom;
> The Pandus' forest-borne disaster,
> And knightly Arjun, dancing master.
> Time brings us woe in countless shapes.
> What savior is there? Who escapes?

> Ah, where is Dasharath, who rose to heaven
> And dwelt its king beside?
> Ah, where King Sagar, he to whom 'twas given
> To bind the ocean's tide?
> Where arm-born Prithu? Where is Manu gone,
> Sun-child (yet suns still rise)?
> Imperious Time awakened them at dawn,
> At evening closed their eyes.

And again:

> Where is Mandhatar, conqueror supreme?
> Where Satyavrat the king?

"And again:

> A noble purpose to attain
> Desiderates extended pain,
> Asks man's full greatness, pluck, and care,
> And loved ones aiding with a prayer.
> Yet if it climb to heart's desire,
> *What man of pride and fighting fire,*
> Of Passion, and of self-esteem
> Can bear the unaccomplished dream?
> His heart indignantly is bent
> (Through its achievement) on content.

"Therefore my heart is at peace. For I saw the undertaking through. Therefore may you now long enjoy this kingdom without a thorn—intent on the safeguarding of your people—your royal umbrella, throne, and glory unshaken through the long succession of son, grandson, and beyond. Remember:

> A king should bring his people ease,
> But he should also aim to please.
> His reign is else of little note,
> A neck teat on a female goat.

And once again:

> Love of virtue, scorn of vice,
> Wisdom—make a kingdom's price.
> Then is Glory proud as slave,
> Then her plumes and pennons brave
> Near the white umbrella wave.

"Nor must you, in the thought, 'My kingdom is won,' shatter your soul with the intoxication of glory. And this because the power of kings is a thing uncertain. Kingly glory is hard to climb as a bamboo-stem; hard to hold, being ready to tumble in a moment, with whatever effort it be held upright; even though conciliated, yet sure to

God-ruling Nahush? Keshav, e'er the gleam
Of science following?
They and their lordly elephants, I ween,
Their cars, their heavenly throne,
By lofty Time conferred, in Time were seen,
And lost through Time alone.

And yet again:

The king, his counselors,
His maidens gay,
His golden groves. Fate stings.
They sink away.

"Thus, having won kingly glory, quivering like the ear of a rogue elephant, take delight in her, but trust in wisdom only."

Here ends Book III, called "Crows and Owls," which treats of peace, war, and the other four expedients. The first verse runs:

Reconciled although he be,
Never trust an enemy,
For the cave of owls was burned,
When the crows with fire returned.

LOSS OF GAINS

Here, then, begins Book IV, called "Loss of Gains." The first verse runs:

> Blind folly always has to pay
> For giving property away
> Because of blandishments and guile—
> The monkey tricked the crocodile.

"How was that?" asked the princes. And Vishnusharman told the story of

THE MONKEY AND THE CROCODILE

On the shore of the sea was a great rose-apple tree that was never without fruit. In it lived a monkey named Red Face.

Now one day a crocodile named Ugly-Mug crawled out of the ocean under the tree and burrowed in the soft sand. Then Red Face said: "You are my guest, sir. Pray eat these rose-apples which I throw you. You will find them like nectar. You know the proverb:

> A fool or scholar let him be,
> Pleasant or hideous to see,
> A guest, when offerings are given,
> Is useful as a bridge to heaven.
>
> Ask not his home or education,
> His family or reputation,

> To give us birth, we need a mother;
> For second birth we need another:
> And friendship's brothers seem by far
> More dear than natural brothers are."

But she said: "You have never refused me before. So I am sure it is a she-monkey. You love her and spend the whole day with her. That is why you will not give me what I want. And when you meet me at night, your sighs are hot as a flame of fire. And when you hold me and kiss me, you do not hug me tight. I know some other woman has stolen into your heart."

Then the crocodile was quite dejected, and said to his wife:

> When I am at your feet
> And at your service, sweet,
> Why do you look at me
> With peevish jealousy?

But her face swam in tears when she heard him, and she said.

> "You love her, you deceiver;
> Your wishes never leave her;
> Her pretty shamming steals upon your heart.
> My rivalry is vain, sir;
> And so I pray abstain, sir,
> From service that is only tricky art.

"Besides, if you do not love her, why not kill her when I ask you? And if it is really a he-monkey, why should you love him? Enough! Unless I eat his heart, I shall starve myself to death in your house."

Now when he saw how determined she was, he was distracted with anxiety, and said: "Ah, the proverb is right.

> Remember that a single grab
> Suffices for a fish or crab,

"But we monkeys live in trees, and your home is in the water. How can I go there? Rather bring your lady here, brother, that I may bow down and receive her blessing."

The crocodile said: "My friend, our home is on a lovely sand bank under the water. So climb on my back and travel comfortably with nothing to fear."

When the monkey heard this, he was delighted and said: "If that is possible, my friend, then hasten. Why delay? Here I am on your back."

But as he sat there and saw the crocodile swimming in the bottomless ocean, the monkey was terribly frightened and said: "Go slow, brother. My whole body is drenched by the great waves."

And the crocodile thought when he heard this: "If he fell from my back, he could not move an inch, the water is so deep. He is in my power. So I will tell him my purpose, and then he can pray to his favorite god."

And he said: "Sir, I have deceived you and brought you to your death, because my wife bade me do it. So pray to your favorite god."

"Brother," said the monkey, "what harm have I done her or you? Why have you planned to kill me?"

"Well," replied the crocodile, "those nectar fruits tasted so sweet that she began to long to eat your heart. That is why I have done this."

Then the quick-witted monkey said: "If that is the case, sir, why didn't you tell me on shore? For then I might have brought with me another heart, very sweet indeed, which I keep in a hole in the rose-apple tree. As it is, I am forlorn in this heart, at being taken to her in vain, without my sweet heart."

When he heard this, the crocodile was delighted and said: "If you feel so, my friend, give me that other heart. And my cross wife will eat it and give up starving herself. Now I will take you back to the rose-apple tree."

Tell Handsome, miss, that Theodore
Will see him in the well no more."

"How was that?" asked the crocodile. And the monkey told the story of

HANDSOME AND THEODORE

There was once a frog-king in a well, and his name was Theodore. One day when tormented by his relatives, he climbed from bucket to bucket up the water-wheel, and finally emerged. Then he thought: "How can I pay those relatives back? For the proverb says:

While one brings comfort in distress,
Another jeers at pain;
By paying both as they deserve,
A man is born again."

With this in mind, he saw a black snake named Handsome crawling out of his hole. And on seeing him, he thought once more: "I will invite that black snake into the well, and clean out all my relatives. For the saying goes:

A sliver draws a sliver out;
Just so the wise employ
Grim foes to slaughter foes; and thus
Turn danger into joy."

Having come to this conclusion, he went to the mouth of the hole and called: "Come out! Come out, Handsome! Come out!" But when the snake heard this, he thought: "Whoever he may be that is calling me, he does not belong to my race. That is no snake's voice. And I have no alliance with anyone else in the living world. So I will just stay here until I am sure who he may be. For the proverb says:

Until you have full information
Of prowess, character, and station,

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But Theodore replied: "No, sir. Come with me. I will show you an easy way into the well. And inside there is a very attractive hole at water-level. There you can lie, and you will find it child's play to finish my relatives."

Then the snake reflected: "Yes, I am old. Now and then, with great effort, I catch one mouse. And often I don't. Yes, yes. The proverb is right:

> When strength is ebbing, dying,
> When friends are gone, and wife,
> The prudent should be trying
> A carpet-slippery life."

After these reflections, he said: "Well, Theodore, if you really mean it, lead the way. We will go together."

"Friend Handsome," said Theodore, "I will take you there by an easy way and show you the resting-place. But you must spare my family. You must not eat any except those I point out."

"My dear fellow," said the snake, "you and I are now friends. Have no fear. I will do nothing but what you wish."

Then he came out of his hole, hugged the frog, and started off with him. So they came to the edge of the well, and the snake went in with the frog by way of the buckets on the water-wheel. Then Theodore settled the black snake in the hole and showed him the relatives. And he ate them all one after another. And lacking relatives, he made up to a few of the friends, and ate them, too, with much circumspection.

Then the snake said: "My dear fellow, I have disposed of your enemies. Please give me something to eat, for you brought me here."

"But, my dear fellow," said Theodore, "you have done what a friend should do. Pray return by way of the bucket ..."

"[illegible]odore," said Handsome, "you make a se-

As muddied garments dirty
All that you sit upon,
So, when one virtue tumbles,
The rest are quickly gone.

Now one day, while eating frogs, he ate a frog named Theodosius, the son of Theodore. And Theodore, seeing him do it, wailed with piercing shrillness. But his wife said:

"Why so shrill? You were still
While you worked your cruel will.
Hope has fled with your dead;
Who will save your hapless head?

So think out a plan of escape this very day, or else a scheme to kill him."

Now in course of time the frogs were finished one and all; only Theodore remained. And then Handsome said: "My dear Theodore, I am hungry and all the frogs are finished. Please give me something to eat, for you brought me here."

Theodore said: "My friend, feel no anxiety on that head while I am alive. If you permit me to leave, I will ersuade the frogs in other wells, and bring them all here."

The snake said: "Well, I can't eat you, for you are like brother. Now if you do as you say, you will be like a ather."

So the frog planned his escape, and left the well, while Handsome waited there, impatient for his return. But ter a long time Handsome said to a lizard that lived in nother hole in the same well: "My dear madam, do me small favor, since Theodore is an old friend of yours. lease go and find him in some pool or other, and take m a message from me. Tell him to return quickly, one if need be, if no other frogs will come. I cannot live

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Now in course of time the frogs were finished one and all; only Theodore remained. And then Handsome said: "My dear Theodore, I am hungry and all the frogs are finished. Please give me something to eat, for you brought me here."

Theodore said: "My friend, feel no anxiety on that head while I am alive. If you permit me to leave, I will persuade the frogs in other wells, and bring them all here."

The snake said: "Well, I can't eat you, for you are like a brother. Now if you do as you say, you will be like a father."

So the frog planned his escape, and left the well, while Handsome waited there, impatient for his return. But after a long time Handsome said to a lizard that lived in another hole in the same well: "My dear madam, do me a small favor, since Theodore is an old friend of yours. Please go and find him in some pool or other, and take him a message from me. Tell him to return quickly, alone if need be, if no other frogs will come. I cannot live

said to the lion: "O King, I am tortured with hunger until I cannot drag one foot after another. So how can I serve you?" "My good Dusty," said the lion, "hunt out some animal that I can kill even in my present state."

So the jackal went hunting, and dragging himself to a nearby village, he saw beside a tank a donkey named Flop-Ear who was choking over the thin and prickly grass. And he drew near and said: "Uncle, my respects to you. It is long since we met. How have you grown so feeble?"

And Flop-Ear answered: "What am I to do, nephew? The laundryman is merciless, and tortures me with dreadful burdens. And he never gives me a handful of fodder. I eat nothing but this prickly grass flavored with dust, and I do not thrive."

"Well, uncle," said the jackal, "I know a lovely spot by a river, all covered with emerald grass. Come there and live with me. I promise you the pleasure of witty conversation."

"Very well said, nephew," answered Flop-Ear, "but village beasts are likely to be killed by forest animals. So what good is your charming spot to me?"

"No, no," said the jackal. "My paws form a cage to protect the spot, and no stranger has entrance there. Besides, there are three unmarried she-donkeys who were tormented just like you by laundrymen. They have now grown plump; they are young and frisky; they said to me: 'Uncle dear, go to some village and bring us a proper husband.' That is why I came to fetch you."

Now when he heard the jackal's words, Flop-Ear felt his limbs quiver with love, and he said: "In that case, my dear sir, lead the way. We will hurry there." For the poet hits the mark when he says:

> You are our only nectar; you,
> O woman, are our poison, too.

stretched out a hand to detain you. That is the whole story. So come back. She has resolved to starve to death for your sake, and she says: 'If Flop-Ear does not marry me, I will plunge into fire or water, or will eat poison. Anyhow, I cannot bear to be separated from him.' So have mercy, and return. If not, you will be a woman-murderer, and the god of love will be angry. For you know:

> Woman is Love's victorious seal,
> Confers all good. If for their weal
> (Supposed) in heaven or for salvation
> Dull men hold her in detestation,
> Love strikes them for their sins forlorn,
> And some turn naked monks, some shorn;
> Some have red garments; others wear
> Skull necklaces, or frowsy hair."

So the donkey, persuaded by this reasoning, started off with him once more. Indeed, the proverb is right:

> Men, knowing better, oft commit
> A shabby deed—so strong is fate.
> But where are they who relish it
> When once it is irrevocate?

Thereupon the donkey, deceived by a hundred arguments of the rascal, came again into the presence, and was straightway killed by the lion, who had prepared his spring beforehand. And then the lion set the jackal on guard, and went himself to the river to bathe. Whereupon the greedy jackal ate the donkey's ears and heart. Now when the lion returned after bathing and repeating the proper prayers, he found the donkey minus ears and heart, and his soul was suffused with wrath, and he said to the jackal: "You scoundrel! What is this unseemly deed? You have eaten ears and heart, and my share is your

Now the king noticed on his brow the horrible scar from the potsherd, and he thought: "Surely, this man is a great hero. He took a wound in front, on his brow." So he bestowed honors and gifts and the like, regarding him more graciously than all others. Even the princes, observing the exceptional favor shown him, cherished an extreme jealousy, yet they feared the king and said not a word.

Now one day there was a review of picked troops. While the elephants were being accoutered and the horses caparisoned and the men inspected, the king took occasion to say to the potter: "O Prince, what is your name? And what your family? In what battle was this wound printed on your brow?"

"Your Majesty," he replied, "by birth I am a potter, and my name is Fight-Firm. This is not a sword-wound. But when I was unsteady with liquor, I was hurrying through a courtyard littered with broken pots, and tumbled over one. Later the scar from the potsherd became a horrible cicatrice."

Then the king reflected: "Good heavens! I was taken in by this potter who seemed a prince. Let a cuffing be administered."

When this had been done, the potter said: "Your Majesty, do not treat me thus, but witness my adroitness in battle." "No, my friend," said the king, "you may be a treasure-house of all the virtues. Yet you must begone. You may have heard the stanza:

> Handsome you are, and valorous;
> You have a scholar's brain:
> But in your family, my boy,
> No elephants are slain."

"How was that?" asked the potter. And the king told the story of

fully started for him, eager to kill. But the jackal-cub said: "Brothers, that is an elephant, an enemy of your race. Don't go near him." With this he ran home. And the other two, seeing their elder brother routed, felt their pluck ooze away. The well-known proverb is right:

> One bold and plucky fighter
> Will give an army pluck:
> One broken, routed blighter
> Diffuses evil luck.

And, indeed,

> This is the very reason why
> Kings look for sturdy fighters,
> Heroic, dauntless, stone-wall men,
> And shun the cowardly blighters.

Later the twin brothers went home, and humorously told their parents how their elder brother had behaved. "Why, you know," said they, "the minute he saw him, he couldn't get far enough quick enough."

When the jackal heard this, wrath entered his spirit. His blossom-lip quivered, his eyes grew red, and a frown made two deep wrinkles on his brow. And he spoke harshly, scolding the twins.

Then the lioness took him aside and admonished him: "You must never, never speak so, my dear. They are your brothers." But her patient pleading filled him with greater anger, and he burst upon her, too: "Do you think me their inferior in courage or beauty or science or application or skill? What right have they to ridicule me? I am certainly going to kill them."

When she heard this outburst, the lioness laughed quietly—for she did not wish him to die—and said:

> "Handsome you are, and valorous;
> You have a scholar's brain.

fully started for him, eager to kill. But the jackal-cub said: "Brothers, that is an elephant, an enemy of your race. Don't go near him." With this he ran home. And the other two, seeing their elder brother routed, felt their pluck ooze away. The well-known proverb is right:

> One bold and plucky fighter
> Will give an army pluck:
> One broken, routed blighter
> Diffuses evil luck.

And, indeed,

> This is the very reason why
> Kings look for sturdy fighters,
> Heroic, dauntless, stone-wall men,
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about for water." And he did as she requested, but when he returned with water, he found her dead.

Since he loved her dearly, he fell into despair, but as he lamented, he heard a voice from heaven, saying: "Brahman, if you will give half your own life, your wife may live." So he performed a ceremony of purification, then gave a half of his own life by repeating the three magic words: "I give life." The moment he spoke, his wife stood up, alive.

So together they drank the water, ate forest-fruits, and started on. Finally, they entered a flower-garden near a city, where the Brahman said to his wife: "Beloved, please stay here until I return with food." And he left her.

Now in the garden was a cripple, turning a water-wheel and singing with a heavenly voice. When she heard the song, she was smitten with love, went to him, and said: "Dear friend, if you do not give me your love, you will be the murderer of a Brahman woman." "But what can you do with an invalid like me?" asked the cripple. "Be still," said she, "you must make me your bride." And hearing her words, he did so. Thereupon she said: "From this moment I give you my person for life. You must accompany us with this understanding." "Very well," said he.

Then when the Brahman returned with food and began to eat with her, she said: "This cripple is hungry. Please give him a bite, too." When this was done, the lady said: "Brahman, when you go alone to another village, I have no one to talk to. Suppose we take this cripple with us." But he replied: "I cannot even carry myself, to say nothing of this cripple." "I will carry him," said she, "if he will get into a basket." And the Brahman agreed, his judgment being bewildered by her artful argument.

One day thereafter, as they rested near a well, the

I left my family for her, ...

and the rest of it."

Then the monkey continued: "There is another little anecdote that is very pat:

> What will not man for woman do,
> When heads are shorn—at odd times, too?
> What will not not man for woman say,
> When those who are not horses, neigh?"

"How was that?" asked the crocodile. And the monkey told the story of

KING JOY AND SECRETARY SPLENDOR

There was once a king named Joy, lord of the sea-girdled earth, whose power and manliness were famed afar, whose footstool was reticulated with interlacing beams of light from the diadems of uncounted hosts of kneeling princes, whose glory was unspotted as the autumn moonbeams. He had a secretary named Splendor, who had absorbed the total truth of all the scientific textbooks, but whose wife pouted in a lovers' quarrel.

"Beloved," said her husband, "tell me the means of appeasing you. I will adopt it without fail." And it cost her a struggle to say: "If you will shave your head and fall at my feet, then I will think of relenting." When he did so, she did so.

Now Joy's wife became angry in just the same way, and would not be appeased though he begged her pardon. Then he said: "Beloved, I cannot live a moment without you. I will fall at your feet and beg your pardon." She said: "If you hold a bit in your mouth and let me climb on your back and drive you, and if, when driven, you neigh like a horse, then I will relent." And this was done.

Next morning Splendor came before the king as he sat in council. And the king asked, when he saw him, "Good Splendor, why is your head shaved at this odd time?" And Splendor answered:

> What will not man for woman do
> When heads are shorn—at odd times, too?
> What will not man for woman say,
> When those who are not horses neigh?

"You simpleton! You, too, are henpecked just lik[e] Joy and Splendor. You tried to find a means of killi[ng] me because your wife asked it. But you were betrayed by your own speech. Yes, the proverb is right:

> [illegible]
> [illegible] words

When this was done, the donkey ate barley to his heart's content. And at dawn the laundryman took him back to the barn. So as time passed, he grew plump. He could hardly squeeze into the stall.

But one day the donkey heard the bray of a she-donkey in the distance. At the mere sound he himself began to bray. Then the farmers perceived that he was a donkey in disguise, and killed him with blows from clubs and stones and arrows.

"And that is why I say:

> However skilful in disguise, ...

and the rest of it."

Now while the monkey was telling these stories to the crocodile, another water-beast came up and said: "Friend crocodile, your wife has starved herself to death."

When the crocodile heard this, he was bewildered in spirit, and lamented: "Oh, what has come upon me, upon hapless me? For the proverb says:

> Where a mother does not dwell
> And a wife who flatters well,
> Better leave the house, and roam
> Forests not so wild as home.

Oh, my friend! Forgive my sins toward you. For I have lost her, and I plan to burn myself alive."

When the monkey heard this, he laughed and said: "Come now! I knew from the very beginning that you were henpecked and in leading-strings. And this proves it. You dunderhead! You despair when you ought to be happy. When a wife like that dies, you ought to give a party. For the proverb says:

> A wife forever nagging
> And falling in a rage,

sibly be contented at home. Her one idea was strange men.

Now a rogue who lived by pilfering, noticed her and said: "You lovely creature, my wife is dead, and I am smitten with love at the sight of you. Pray enrich me with love's perfect treasure."

And she said: "You beautiful man, if you feel that way, my husband has a great deal of money, and he is so old that he cannot stir. I will bring it, so that I may go somewhere with you and enjoy the delights of love."

"That is satisfactory to me," he replied. "Suppose you hasten to this spot at dawn, so that we may go together to some fascinating city where life may bear for me its perfect fruit." "Very well," she agreed, and went home with laughing countenance.

Then at night, while her husband slept, she took al the money, and reached the rendezvous at dawn. The rogue, for his part, put her in front, started south, and traveled two leagues, gaily enjoying the delights of conversation with her. But when he saw a river ahead, he reflected: "What am I to do with this middle-aged female? Besides, someone might perhaps pursue her. I will just take her money and be off."

So he said to her: "My dear, this is a great river, hard to cross. I will just take the money and put it safe on the far bank, then return to carry you alone on my back, and so transport you in comfort." "Do so, my beloved," said she.

So he took the money to the last penny, and then he said: "Dearest, hand me your dress and your wrap, too, so that you may travel through the water unembarrassed." And when she did so, the rogue took the money and the two garments and went to the place he had in mind.

Then the farmer's wife sat down woebegone on the river-bank, digging her two hands into her throat. At

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Then at night, while her husband slept, she took all the money, and reached the rendezvous at dawn. The rogue, for his part, put her in front, started south, and traveled two leagues, gaily enjoying the delights of conversation with her. But when he saw a river ahead, he reflected: "What am I to do with this middle-aged female? Besides, someone might perhaps pursue her. I will just take her money and be off."

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that moment a she-jackal came to the spot carrying a piece of meat. As she came up and peered about, a great fish leaped from the water and was stranded on the bank. On spying him, she dropped the meat and darted at the fish. Whereupon a vulture swooped from the sky and flew off with the meat. And the fish, perceiving the jackal, struggled into the river. So the she-jackal had her pains for nothing; and as she gazed after the vulture, the naked woman smiled and said:

'You poor she-jackal!

"How true it is that misfortunes never come singly! Well, shall I fight him? Or shall I address him with soft conciliation, and get him out of the house? Or shall I try intrigue? Or bribery? Ah, here is my monkey friend. I will ask him. For the proverb says:

> Ask aid of kindly teachers, man,
> The kind you ought to ask.
> Their counsel leads to sure success,
> Whatever be your task."

After these reflections, he put the question to the monkey, who had climbed back into the rose-apple tree. "Oh, my friend," said he, "see how unlucky I am. For now my very house is seized and held by a powerful crocodile. Therefore I put it to you. Tell me, what am I to do? Is this the place for soft conciliation or one of the other three devices?"

But the monkey said: "You ungrateful wretch! Why do you still pursue me, though I asked you not to? You are a fool, therefore I will not even give you good advice. For the proverb says:

> Give counsel only when it fits
> To such as seek the best.
> The foolish monkey broke to bits
> The sparrow's cozy nest.

"How was that?" asked the crocodile. And the monkey told the story of

THE PERT HEN-SPARROW

In a certain wood lived a sparrow and his wife who had built their nest on the branch of a tree. One day in the month of February a monkey took shelter under the tree; for he had been caught in an unseasonable hailstorm, and his body shivered to the slightest breeze. Since his teeth were making music and his face was woe-

wife, why throw friends, relatives, and such into the ocean just because she asks it?"

And the crocodile answered: "My dear fellow, it is all true. Yet consider the maxim, 'Seven words make friendship,' and give me a bit of good advice. For there is a saying:

> Disaster cannot threaten
> The man of sterling worth
> Who offers helpful counsel—
> In heaven, or on earth.

So, though I did you a wrong, I beg you to show forgiveness by giving good advice. You know the proverb:

> *And is there any saintlihood*
> In recompensing good with good?
> But worthy men go seeking still
> The saints returning good for ill."

Then the monkey said: "Well, well, my good fellow, I advise you to go and fight him. For there is a saying:

> *Sway patrons with obeisance;*
> In heroes raise a doubt;
> Fling petty bribes to flunkeys;
> With equals, fight it out."

"How was that?" asked the crocodile. And the monkey told

HOW SUPERSMART ATE THE ELEPHANT

There was once a jackal named Supersmart in a part of a forest. One day he came upon an elephant that had died a natural death in the wood. But he could only stalk about the body; he could not cut through the tough hide.

At this moment a lion, in his wanderings to and fro, came to the spot. And the jackal, spying him, obsequi-

slow in returning, don't give him any news of me." With these words he decamped.

When the tiger had gone, a leopard appeared. And the jackal thought when he saw him: "Here comes Spot. He has powerful teeth. So I will use him to cut into this elephant-hide."

With this in mind, he said: "Well, nephew, where have you been this long time? And why do you seem so hungry? You come as my guest, according to the proverb:

> A guest in need
> Is a guest indeed.

Now here lies this elephant, killed by a lion who appointed me its guardian. But for all that, you may enjoy a square meal of elephant-meat, provided you cut and run before he gets back."

"No, uncle," said the leopard, "if things stand so, this meat is not healthy for me. You know the saying:

> A man to thrive
> Must keep alive.

Never eat a thing that doesn't sit well on the stomach. So I will be off." "Don't be timid," said the jackal. "Pluck up courage and eat. I will warn you of his coming while he is yet a long way off." So the leopard did as suggested, and the jackal, as soon as he saw the hide cut through, called out: "Quick, nephew, quick! Here comes the lion." Hearing this, the leopard vanished also.

Now while the jackal was eating meat through the opening cut by the leopard, a second jackal came on the scene in a great rage. And Supersmart, esteeming him an equal whose prowess was a known quantity, recited the stanza:

ouse every day, and ate his fill from a diversified bill of
re. But as he left the house, other dogs, drunk with
istocratic spleen, closed in from all sides, and tore him
in every limb with their fangs.

Then he thought: "Better one's native land, where
one lives at peace even in times of famine, and no one
picks a quarrel. It is better to return to my own city."
Having thus reasoned it through, he returned to his
own place.

Then his relatives asked him questions, as one return-
ing from foreign parts: "Come now, tell us about it.
What is the country like? How do the people behave?
What do they eat? And what are their habits?"

And he replied: "Why speak of the country?

> The food is very good to eat
> And does not lack variety;
> While easy going women meet
> You in the town's society;
> But kinsmen in that foreign street
> Are wanting in sobriety."

So the crocodile, having received his friend's advi
resolved to die if need be, said farewell to the monk
and went to his own house. There he joined batue
with the desperate ruffian who had forced a way in, put
his reliance in resolute valor, and killed him. So he re-
covered his home and lived there happily for a long
time.

Yes, the proverb is right:

> Shun pleasant days that listless pass,
> The joy that hides
> In sloth. For deer can eat the grass
> That fate provides.

Here ends Book IV, called "Loss of Gains." The first
verse runs

BOOK V

ILL-CONSIDERED ACTION

Here, then, begins Book V, called "Ill-considered Action." The first verse runs:

> Deeds ill known, ill-recognized,
> Ill-accomplished, ill-devised—
> Thought of these let no man harbor;
> Take a warning from the barber.

"How was that?" asked the princes. And Vishnusharman told the following story.

In the southern country is a city called Trumpet-Flower. In it lived a merchant named Jewel, who lost his fortune by the decree of fate, though his life was given to the pursuit of virtue, money, love, and salvation. The loss of property led to a series of humiliations, so that he sank into utter despondency. And one night he reflected: "A curse, a curse upon this state of poverty! For the proverb says:

> Conduct, patience, purity,
> Manners, loving kindness, birth,
> After money disappears,
> Cease to have the slightest worth.
>
> Wisdom, sense, and social charm,
> Honest pride and self-esteem,
> After money disappears,
> All at once become a dream.

At this moment a barber arrived to manicure his wife's nails. And while the barber was busy with his manicuring, the Jain monk suddenly appeared. When Jewel perceived the monk, he was delighted and struck him on the head with a stick of wood that lay handy. Whereupon the monk turned to gold and immediately fell to the ground.

The merchant then set him up in the middle of the house, and said to the barber, after handing him a tip: "My good fellow, you must not tell anybody what has happened in our house." To this the barber assented, but when he reached home, he thought: "Surely, all these naked fellows turn to gold when clubbed on the head. So tomorrow morning I, too, will invite a lot of them and club them to death, in order to get a lot of gold." And the day and the night dragged away as he meditated his plan.

In the morning he rose and went to a Jain monastery, arranged his upper garment, circumambulated the Conqueror thrice, sought the ground with his knees, laid his garment's hem over the gateway of his mouth, made a profound obeisance, and with an ear-piercing voice intoned the following hymn:

> "The saints victorious endure
> Who live by saving knowledge pure,
> Who sterilize the mind within
> By mind, against the seed of sin.

And further:

> The tongue that praiseth Him is blest;
> The heart, in Him that seeketh rest;
> The hands are blest, and only they,
> That e'er to Him due homage pay."

After chanting other hymns also to the same effect, but in great variety, he sought out the abbot and dropped

on his knees and hands, saying: "Greetings, Your Reverence." From the abbot he received a benediction for the increase of his virtue, likewise instructions for a vow that involved the practice of celibacy. Then he said devoutly: "Holy sir, when you take your pious walk to-day, pray come to my house with your whole company of monks."

"My dear neophyte," replied the abbot, "you know the holy law. How can you speak so? Do you take us for Brahmans, that you invite us to eat? No, we wander each day just as it happens, and when we see a pious neophyte, enter his house. Begone! Never speak so

[illegible]

heir heads broken and began to bawl. But when ers in the citadel heard the howling, they said: ell! What is this tremendous hubbub in the mid-own? Come along!" So they all scampered and *monks rushing from the* barber's house, blood g over their bodies. And being asked what it hey told exactly how the barber had behaved. e soldiers fettered the barber and carried him ourt together with such monks as had survived ghter. There the judges questioned him: "Come at means this shameful deed by you committed?" e replied: "Gentlemen, what else could I do?" ith this he related the behavior of Jewel.

judges therefore despatched a summonser, who d with Jewel. And they questioned him: "Mer-why did you kill a certain Jain monk?" And he gave a full account of the original monk. Where-they said: "Well, well! Let this villainous barber paled. *For his act was ill advised.*"

en this had been done, they observed:

> Deeds ill-known, ill-recognized,
> Ill accomplished, ill-advised—
> Thought of these let no man harbor;
> Take a warning from the barber.

there is sound sense in this:

> Let the well-advised be done;
> Ill-advised leave unbegun;
> Else, remorse will be le 'oose,
> As with lady and mungoose.

ow was that?" asked Jewel. And they told the story o

THE LOYAL MUNGOOSE

There was once a Brahman named Godly in a certai w... His ... ife mothered a single son and a mungoos

At this moment the Brahman came home with a dish of rice gruel which he had got from someone in his begging tour, and saw his wife bitterly lamenting her son, the mungoose. "Greedy! Greedy!" she cried. "Because you did not do as I told you, you must now taste the bitterness of a son's death, the fruit of the tree of your own wickedness. Yes, this is what happens to those blinded by greed. For the proverb says:

> Indulge in no excessive greed
> (A little helps in time of need)—
> A greedy fellow in the world
> Found on his head a wheel that whirled."

"How was that?" asked the Brahman. And his wife told the story of

THE FOUR TREASURE-SEEKERS

In a certain town in the world were four Brahmans who lived as the best of friends. And being stricken with utter poverty, they took counsel together: "A curse, a curse on this business of being poor! For

> The well-served master hates him still;
> His loving kinsmen with a will
> Abandon him; woes multiply,
> While friends and even children fly;
> His high-born wife grows cool; the flash
> Of virtue dims; brave efforts crash—
> For him who has no ready cash.

And again:

> Charm, courage, eloquence, good looks,
> And thorough mastery of books
> (If money does not back the same)
> Are useless in the social game.

And as she loved little ones, she cared for the mungoose also like a son, giving him milk from her breast, and salves, and baths, and so on. But she did not trust him, for she thought: "A mungoose is a nasty kind of creature. He might hurt my boy." Yes, there is sense in the proverb:

> A son will ever bring delight,
> Though bent on folly, passion, spite,
> Though shabby, naughty, and a fright.

One day she tucked her son in bed, took a water-jar, and said to her husband: "Now, Professor, I am going for water. You must protect the boy from the mungoose." But when she was gone, the Brahman went off somewhere himself to beg food, leaving the house empty.

While he was gone, a black snake issued from his hole and, as fate would have it, crawled toward the baby's cradle. But the mungoose, feeling him to be a natural enemy, and fearing for the life of his baby brother, fell upon the vicious serpent halfway, joined battle with him, tore him to bits, and tossed the pieces far and wide. Then, delighted with his own heroism, he ran, blood trickling from his mouth, to meet the mother; for he wished to show what he had done.

But when the mother saw him coming, saw his bloody mouth and his excitement, she feared that the villain must have eaten her baby boy, and without thinking twice, she angrily dropped the water-jar upon him, which killed him the moment that it struck. There she left him without a second thought, and hurried home, where she found the baby safe and sound, and near the cradle a great black snake, torn to bits. Then, overwhelmed with sorrow because she had thoughtlessly killed her benefactor, her son, she beat her head and breast.

keeping a pawnshop, (4) getting regular customers, (5) a stock company, (6) *articles de luxe* such as perfumes, (7) foreign trade.

"Now the economists say:

> False weights and boosting prices to
> An overshameless sum
> And constant cheating of one's friends
> Are fit for social scum.

And again:

> Deposits in the house compel
> The pawnshop man to pray:
> If you will kill the owner, Lord,
> I'll give you what you say.

Likewise:

> The holder of a stock reflects
> With glee, though one of many:
> The wide world's wealth belongs to me;
> No other gets a penny.

Furthermore:

> Perfumery is first-class ware;
> Why deal in gold and such?
> Whate'er the cost, you sell it for
> A thousand times as much.

"Foreign trade is the affair of the capitalist. As the book says:

> Wild elephants are caught by tame:
> So money kings, devising
> A trap for money, capture it
> With far flung advertising.

> The brisk commercial traveler,
> Who knows the selling game,

It bubbles from hell.
Man's effort (sufficiently great)
Can equal the wonders of fate.

And again:

> Success complete
> In any feat
> Is sure to bless
> True manliness.
> Man's effort (sufficiently great)
> Is just what a dullard calls fate.

> There is no toy
> Called easy joy,
> But man must strain
> To body's pain.
> Even Vishnu embraces his bride
> With arms that the churn-stick has tried.

"So disclose to us some method of getting money, whether crawling into a hole, or placating a witch, or living in a graveyard, or selling human flesh, or anything. You are said to have miraculous magic, while we have boundless daring. You know the saying:

> Only the great can aid the great
> To win their heart's desire:
> Apart from ocean, who could bear
> The fierce subaqueous fire?"

So the magician, perceiving their fitness as disciples, made four magic quills, and gave one to each, saying: "Go to the northern slope of the Himalaya Mountains. And wherever a quill drops, there the owner will certainly find a treasure."

Now as they followed his directions, the leader's quill dropped. And on examining the spot, he found the soil all copper. So he said: "Look here! Take all the copper

sir," said he, "what is the meaning of this?" "In the very same way," replied the other, "it settled on my head." "But," said the Brahman, "when will it go away? It hurts terribly."

And the fellow said: "When someone who holds in his hand a magic quill such as you had, arrives and speaks as you did, then it will settle on his head." "Well," said the Brahman, "how long were you here?" And the other asked: "Who is king in the world at present?" On hearing the answer, "King Vinavatsa," he said: "When Rama was king, I was poverty stricken, procured a magic quill, and came here, just like you. And I saw another man with a wheel on his head and put a question to him. The moment I asked a question (just like you) the wheel left his head and settled on mine. But I cannot reckon the centuries."

Then the wheel bearer asked: "My dear sir, how, pray, did you get food while standing thus?" "My dear sir," said the fellow, "the god of wealth, fearful lest his treasures be stolen, prepared this terror, so that no magician might come so far. And if any should succeed in coming, he was to be freed from hunger and thirst, preserved from decrepitude and death, and was merely to endure this torture. So now permit me to say farewell. You have set me free from a sizable misery. Now I am going home." And he went.

After he had gone, the gold-finder, wondering why his companion delayed, eagerly followed his footprints. And having gone but a little way, he saw a man whose body was drenched with blood, a man tortured by a cruel wheel whirling on his head—and this man was his own companion. So he came near and asked with tears: "My dear fellow, what is the meaning of this?" "A whim of fate," said the other. "But tell me," said he, "what has happened." And in answer to his question, the other told the entire history of the wheel.

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And the fellow said: "When someone who holds in his hand a magic quill such as you had, arrives and speaks as you did, then it will settle on his head." "Well," said the Brahman, "how long were you here?" And the other asked: "Who is king in the world at present?" On hearing the answer, "King Vinavatsa," he said: "When Rama was king, I was poverty stricken, procured a magic quill, and came here, just like you. And I saw another man with a wheel on his head and put a question to him. The moment I asked a question (just like you) the wheel left his head and settled on mine. But I cannot reckon the centuries."

Then the wheel bearer asked: "My dear sir, how, pray, did you get food while standing thus?" "My dear sir," said the fellow, "the god of wealth, fearful lest his treasures be stolen, prepared this terror, so that no magician might come so far. And if any should succeed in coming, he was to be freed from hunger and thirst, preserved from decrepitude and death, and was merely to endure this torture. So now permit me to say farewell. You have set me free from a sizable misery. Now I am going home." And he went.

After he had gone, the gold-finder, wondering why his companion delayed, eagerly followed his footprints. And having gone but a little way, he saw a man whose body was drenched with blood, a man tortured by a cruel wheel whirling on his head—and this man was his own companion. So he came near and asked with tears: "My dear fellow, what is the meaning of this?" "A whim of fate," said the other. "But tell me," said he, "what has happened." And in answer to his question, the other told the entire history of the wheel.

ture, dead. Let us bring it to life by means of the scholarship we have honestly won."

Then the first said: "I know how to assemble the skeleton." The second said: "I can supply skin, flesh, and blood." The third said: "I can give it life."

So the first assembled the skeleton, the second provided skin, flesh, and blood. But while the third was intent on giving the breath of life, the man of sense advised against it, remarking: "This is a lion. If you bring him to life, he will kill every one of us."

"You simpleton!" said the other, "it is not I who will reduce scholarship to a nullity." "In that case," came the reply, "wait a moment, while I climb this convenient tree."

When this had been done, the lion was brought to life, rose up, and killed all three. But the man of sense, after the lion had gone elsewhere, climbed down and went home.

"And that is why I say:

> Scholarship is less than sense, ...

and the rest of it."

But the wheel-bearer, having heard the story, retorted: "Not at all. The reasoning is at fault. For creatures of very great sense perish if stricken by fate, while those of very meager intelligence, if protected by fate, live happily. There is a stanza:

> While Hundred-Wit is on a head,
> While Thousand-Wit hangs limp and dead,
> Your humble Single-Wit, my dear,
> Is paddling in the water clear."

"How was that?" asked the gold finder. And the wheel-bearer told the story of

to another body of water. At dawn the next day came the fish-catchers, who seemed the servants of Death, and inclosed the pond with nets. And all the fishes, turtles, frogs, crabs, and other water-creatures were caught in the nets and captured. Even Hundred-Wit and Thousand-Wit fell into a net and were killed, though they struggled to save their lives by fancy turns.

On the following day the fishermen gleefully started home. One of them carried Hundred-Wit, who was heavy, on his head. Another carried Thousand-Wit tied to a cord. Then the frog, safe in the throat of a cistern, said to his wife: "Look, darling, look!

> While Hundred-Wit is on a head,
> While Thousand-Wit hangs limp and dead,
> Your humble Single-Wit, my dear,
> Is paddling in the water clear."

"And that is why I say that intelligence is not the sole determinant of fate."

Then the gold finder said: "It may be so. Yet a friend's advice should not be disregarded. But what happened? Spite of my dissuasion, you would not stop, such was your greed and pride in your scholarship. Yes, there is sense in the stanza:

> Well sung, uncle! Why would you
> Not stop when I told you to?
> What a necklace! Yes, you wear
> Music medals rich and rare."

"How was that?" asked the wheel-bearer. And the other told the story of

THE MUSICAL DONKEY

In a certain town was a donkey named Prig. In the daytime he carried laundry packages, but was at liberty to wander anywhere at night. One night while wander-

> Of pitches there are forty-nine,
> Three measures, also pauses three;
>
> Caesuras three; and thirty-six
> Arrangements of the notes, in fine;
> Six apertures; the languages
> Are forty; sentiments are nine.
>
> One hundred songs and eighty-five
> Are found in songbooks, perfect, pure,
> With all accessories complete,
> Unblemished in their phrasing sure.
>
> On earth is nothing nobler found,
> Nor yet in heaven, than vocal song;
> The singing Devil soothes the Lord,
> When quivering strings the sound prolong.

"After this, how can you think me lacking in educated taste? How can you try to hinder me?"

"Very well, uncle," said the jackal. "I will stay by the gap in the hedge, and look for farmers. You may sing to heart's content."

When he had done so, the donkey lifted his neck and began to utter sounds. But the farmers, hearing the bray of a donkey, angrily clenched their teeth, snatched cudgels, rushed in, and beat him so that he fell to the ground. Next they hobbled him by fastening on his neck a mortar with a convenient hole, then went to sleep. Presently the donkey stood up, forgetting the pain as donkeys naturally do. As the verse puts it:

> With dog, and ass, and horse,
> And donkey more than most,
> The pain from beatings is
> Immediately lost.

Then with the mortar on his neck, he trampled the hedge and started to run away. At this moment the

ing in the fields he fell in with a jackal and made friends. So the two broke through a hedge into cucumber-beds, and having eaten what they could hold of that comestible, parted at dawn to go home.

One night the egotistical donkey, standing among the cucumbers, said to the jackal: "See, nephew! The night is marvelously fine. I will contribute a song. What sentiment shall my song express?" "Don't, uncle," said the jackal. "It might make trouble, seeing that we are on thieves' business. Thieves and lovers should keep very quiet. As the proverb says:

> No sleepyhead should pilfer fur,
> No invalid, rich provender,
> No sneezer should become a thief—
> Unless they wish to come to grief.

"Besides, your vocal music is not agreeable, since it resembles a blast on a conch-shell. The farmers would hear you from afar, would rise, and would fetter or kill you. Better keep quiet and eat."

"Come, come!" said the donkey. "Your remarks prove that you live in the woods and have no musical taste. Did you never hear this?

> Oh, bliss if murmurs sweet to hear
> Of music's nectar woo your ear
> When darkness flees from moonlight clear
> In autumn, and your love is near."

"Very true, uncle," said the jackal. "But your bray is harsh. Why do a thing that defeats your own purpose?" "Fool, fool!" answered the donkey. "Do you think me ignorant of vocal music? Listen to its *systematization*, as follows:

> Seven notes, three scales, and twenty-one
> Are modulation said to be;